ECONOMIC GEOLOGY

VOL. XXIX DECEMBER, 1934 No. 8

TEMPERATURE RELATIONS TO ORE DEPOSITION.

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ABSTRACT.

This article presents a series of diagrams illustrating in a quantitative manner the cooling of a batholith following intrusion. They are constructed to illustrate the cooling of the Boulder batholith of Montana and the inferences drawn from them are compared with the observed facts of ore occurrence.

INTRODUCTION.

FOLLOWING intrusion of a magma and during its cooling, differentiation, and crystallization, there are changing conditions under which various types of ore deposits are formed. Magmatic segregations are considered to result from the differentiation of the parent magma. Later the metalliferous lodes are formed, commonly occupying restricted positions near the roofs or tops of their intrusives, and in many cases showing a zonal arrangement outward from the igneous source. Describing such deposits, Spurr [1] in 1907 advanced the zonal theory of primary deposition for certain ores; and Emmons [2] in 1924 clearly portrayed the space relations of such lodes.

Causes of primary ore deposition which have been stressed as probably being most important are temperature, pressure, and the physico-chemical nature of the mineralizing solutions. These factors are affected by rock character, structural conditions, and other variables.

[1] Spurr, J. E.: Theory of Ore Deposition. ECON. GEOL., vol. 2, pp. 781–795, 1907.

[2] Emmons, W. H.: Primary Downward Changes in Ore Deposits. Trans. Amer. Inst. Min. Eng., vol. LXX, pp. 964–997, 1924.

The apparently dominant agents controlling the formation of some deposits appear to be of slight importance in other cases. For instance, the reducing action of carbon may cause the localization of ore bodies in carbonaceous shales, as illustrated by the silver veins of the Animikee slate in the Silver Islet Mine.[3]

The importance of temperature relations to ore deposition has frequently been emphasized, and it is the purpose of this paper to attempt a quantitative analysis of this factor.

In order to limit the number of variables under consideration, particular attention is directed to those ore bodies that display a zonal distribution outward from an igneous source. The Boulder batholith of Montana affords a good example and is described in the excellent paper by Billingsley and Grimes.[4]

The diagrams described below were constructed to illustrate the cooling of this batholith.

COOLING OF A BATHOLITH.

Fig. 1 portrays in a quantitative manner the cooling of the contact zone of a batholith. Figs. 2–4 are adaptations from Fig. 1, to emphasize different effects of this cooling.

The curves of Fig. 1 were constructed to represent the cooling of the Boulder batholith of Montana from a mathematical consideration of the effects of conduction of heat from a cooling mass. The equation used, developed by Ingersoll and Zobel,[5] is:[6]

$$\theta=\frac{\theta_0}{r\sqrt{\pi}}\left\{\int_{-r/2h\sqrt{t}}^{(R-r)/2h\sqrt{t}}(r+2h\sqrt{t}\beta)e^{-\beta^2}d\beta-\int_{+r/2h\sqrt{t}}^{(R+r)/2h\sqrt{t}}(-r+2h\sqrt{t}\beta)e^{-\beta^2}d\beta\right\}.$$

[3] Weed, W. H.: Influence of Country Rock on Mineral Veins. Bull. Amer. Inst. Min. Eng., vol. 31, p. 650, 1901.

[4] Billingsley, Paul, and Grimes, J. A.: Ore Deposits of the Boulder Batholith of Montana. Bull. Amer. Inst. Min. Eng., vol. 58, pp. 284–368, 1918.

[5] Ingersoll, L. R., and Zobel, O. J.: Mathematical Theory of Heat Conduction, p. 128. Ginn & Co., 1913.

[6] T. S. Lovering presented a paper at the forty-sixth annual meeting of the Geological Society of America in Chicago, Dec. 30, 1933, entitled "A Simple Method of Applying the Mathematical Theory of Heat Conduction to Some Geological Problems." His paper discusses and describes the construction of curves illustrating heat conduction from intrusives and extrusives of various sizes.

θ, temperature at any chosen point after a certain lapse of time; θ_0, initial temperature of batholith (assuming wall rock is 0°); R, radius of intrusive in centimeters; r, R $\pm$ distance to any chosen point from boundary surface or roof of batholith; h, diffusivity (thermometric conductivity); t, lapse of time in seconds; β, variable of integration.

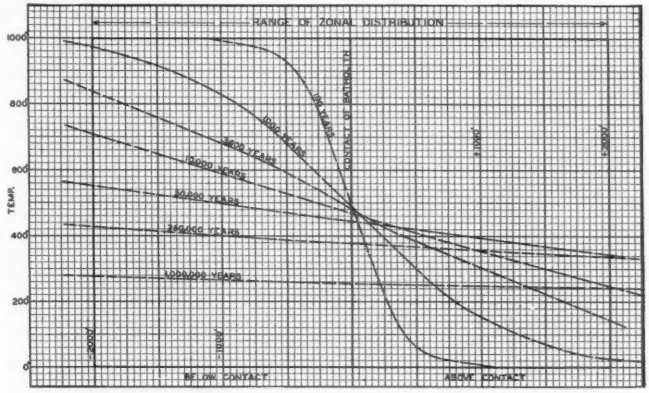

FIG. 1. Curves to illustrate cooling of the contact zone of the Boulder batholith of Montana following intrusion.

The values used in the equation are:

$\theta_0 = 1000°$. This choice,[7] if not a close approximation, will merely change the scale of the graph. It does not affect the form of the curves.

$R = 10$ Miles. The surface extent of the Boulder batholith is about 50 miles by 75 miles.

$h = \sqrt{.0152}$ h for granite $= \sqrt{.0155}$.

By solving θ for a sufficient number of points, the curves shown in Fig. 1 were constructed.

It should be emphasized that this equation was developed to fit the requirements of a laccolith, and when applied to a batholith, gives the maximum rate of cooling possible for the assumed

[7] At Vesuvius, temperatures from 1015° to 1040° have been observed. See Perrett: The Vesuvius Eruption of 1906. Carnegie Inst. Pub. 339, p. 132. Temperatures as high as 1185° have been measured in the lava lake of Kilauea. See Jagger: Amer. Jour. Sci., vol. XLIV, p. 214, 1917. These temperatures are for molten basic rock at the surface and may be higher than would prevail in more acid rocks at depth.

thickness. Furthermore, minimum temperatures are indicated for the enclosing rock, since no allowance has been made for increase of temperature resulting from convection or escape of fluids.

In Fig. 1 the ordinate represents temperature and the abscissa represents distances *below* and *above* the contact of the batholith. Each curve shows the temperature at any point on it at the time specified, the time being measured from the time of intrusion.

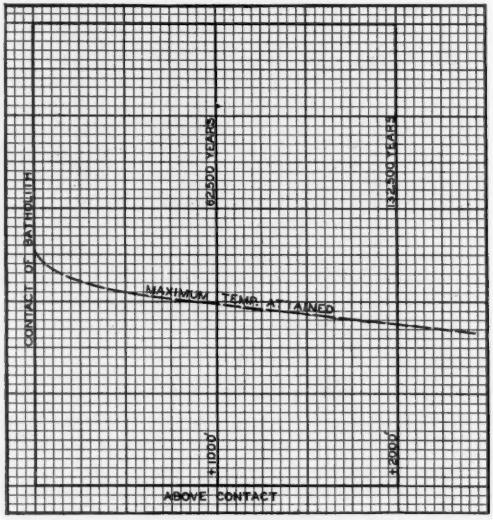

FIG. 2. Curve showing maximum temperature attained above the contact.

The range covered by the diagram, namely, 2,000 feet (below) to 2,000 feet (above) the contact, includes most of the range within which veins showing zonal distribution have been found in and near the Boulder batholith.

INFERENCES DERIVED FROM COOLING CURVES.

1. The cooling of the batholith is a very slow process extending into millions of years.

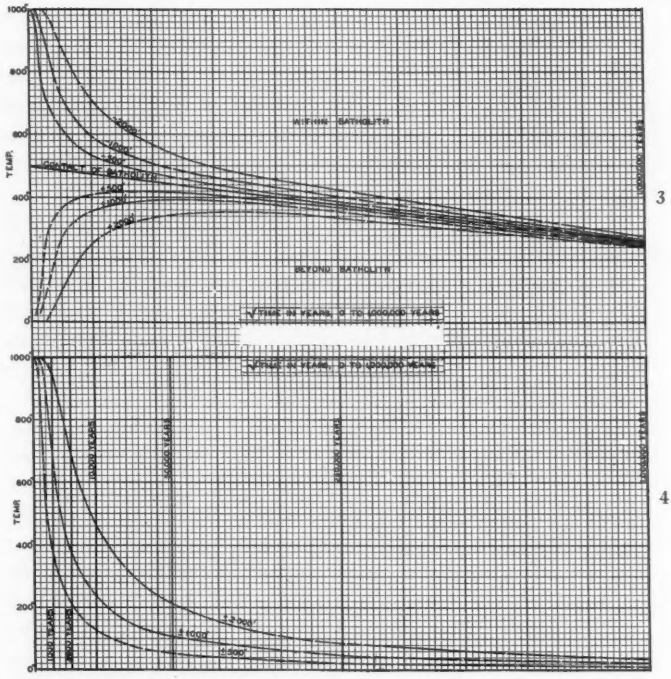

FIG. 3. Curves indicating change of temperature at different locations with lapse of time.

FIG. 4. Curves indicating difference in temperature between definite distances above and below batholith-contact with lapse of time.

2. The temperature of the boundary surface (or roof of the batholith) rapidly falls to one-half the initial value [8] and then cools slowly.

3. There is a sharp temperature gradient near the contact of the batholith which remains for thousands of years.

[8] The initial temperature of the boundary surface would be somewhat higher than Fig. 1 indicates, for the conductivity of hot igneous rock is considerably greater than that of cold; although in order to be able to handle the problem, the thermal constants are considered the same. The error introduced by assuming the diffusivity to be the same becomes less and less as the cooling proceeds.

4. Within the batholith there is persistent cooling, but above it the temperature first rises to a maximum, followed by slow cooling. (Fig. 3.) This outward progressive rise and fall of temperature for all points above the batholith is here designated as the advance of the "heat wave." There is no "trough" behind the "crest" of this "heat wave," but a continuous outward decreasing temperature gradient.

5. The crest of the heat wave (maximum temperature attained) travels outward very slowly. Fig. 2 indicates the maximum temperature reached above the contact for a distance of 2,000 feet.

6. In advance of the crest of the heat wave, temperatures are rising and compression will be increasing; behind the heat wave, cooling occurs accompanied by contraction and the development of tensional stresses.

7. The maximum drop in temperature occurs within the batholith itself. (Fig. 1.) The relative drops in temperature near the contact also indicate proportionately the contractional or tensional strains developing as a result of cooling. These tensional stresses are at a maximum within, but near, the contact. They decrease in intensity outward, to zero at the crest of the heat wave.

8. The range of temperature between the same vertical locations decreases with lapse of time. Also, behind the crest of the heat wave, definite temperatures migrate downward as cooling proceeds.

APPLICATION OF ABOVE INFERENCES.

These curves and the inferences drawn from them prove little or nothing when applied to any theory of ore deposition. However, it is believed that they indicate the limits to which temperature might influence the location and formation of metalliferous veins.

1. It has been demonstrated that the extent of cooling which follows intrusion varies considerably within and beyond the contact of the intrusive (Fig. 1). If similar co-efficients of expansion be assumed for both the intruded and intrusive rock, it is

evident that the tensional stresses of contraction are unequal for different locations near the contact of the intrusive. They are more intense within the intrusive, they decrease greatly above the contact, and die out at the crest of the heat wave, beyond which a rising temperature gradient exists with accompanying compressional forces. Therefore, the development of fractures or fissures of tensional origin should be restricted to the zone within the crest of the heat wave. If the limits of these fissures limit the extent of fissure mineralization, this is a partial explanation for the restricted position of these lodes near the roofs of their parent intrusives. However, with lapse of time, there is a progressive advance outward of the heat wave, but, it is believed, a retreat inward of the zone of mineralization.

If a balance was reached between the tensional stresses resulting from contraction, aided by the inherent pressure of mineralizing solutions as against the tensile strength of the inclosing rocks, there would be two zones, one susceptible to fracture or disruption, beyond which the rocks would, to a considerable extent, dam or restrain the solutions and tend to maintain pressures, except for slow diffusion or gradual escape. Under such conditions the effects of change of temperature should be more pronounced.

If the solutions could reach the surface with accompanying release of pressure, the resulting effects on the solubility of the solutions might far offset any changes due to decreasing temperature, and a new set of controlling factors would limit the zone of mineralization.

2. Under ideal conditions favoring temperature as the dominant factor controlling the solubility of mineralizing solutions, the sequence of a period of mineralization, as indicated by the cooling curves, should be somewhat as follows:

The first ore to form would be located in that zone where the temperature is favorable to initiate crystallization or deposition of the minerals occurring in the ore-bearing solutions. Those minerals having the least solubility would form in the higher-temperature portion of this zone.

Ore veins forming at later stages would occupy successively

lower horizons and should have a greater vertical distribution in order to cover the same temperature range.

Assume, for the purpose of illustration, that the earliest mineralization is restricted to a zone extending from 500 feet to 2,000 feet above the intrusive contact at a time when the heat wave has advanced outward 2,000 feet. This would be after cooling had progressed for 132,000 years, and the temperature range for this 1,500 feet would be 45°, from 395° to 350°.

At a later stage, when the contact of the intrusive has cooled to 350°, a temperature of 395° exists at a depth of about 2,000 feet below the contact, an increase in range of 500 feet. Fig. 3 shows this to be after 360,000 years of cooling.

Actually, the rock temperatures would initially be cooler than the ore-bearing solutions, and the difference of these temperatures would be governed by the rate of flow of the solutions. The slower the movement, the less would be this difference.

3. It is axiomatic that, outward from the source of heat, there is *always a decreasing temperature,* although there is a rising temperature for all points above the crest of the heat wave.

Following a period of mineralization, renewed igneous activity could initiate a new heat wave, the net result of which would be to increase or advance temperatures outward, and any subsequent mineralization might form at a higher horizon than previously. This might superimpose higher-temperature minerals upon a former low-temperature zone. Conversely, with a falling temperature, such as prevails behind the crest of the heat wave, lower-temperature minerals might be superimposed upon a former higher-temperature zone. Thus, a reversal in the order of formation of ore minerals deposited in the same horizon could result from mineralization which was initiated in advance of the heat wave and continued after the crest of the heat wave passed this horizon. However, no reversal in the sequence of zonal distribution, such as from copper-zinc-lead to lead-zinc-copper can be attributed to a rising temperature because no such thing as a rising temperature gradient outward from the source of heat is possible.

ORE DEPOSITS OF THE BOULDER BATHOLITH.

In order to compare the above suggested trends resulting from the control of ore deposition by temperature, with the observed occurrence of some deposits, a brief outline of the fissure veins of the Boulder batholith follows. This information has been obtained from the paper by Billingsley and Grimes.[9]

Granite Stage.—The major mass of the Boulder batholith is a quartz-monzonite, which was intruded while still warm by widespread local intrusions of aplite comprising possibly 8 or 10 per cent. of the total mass. Quartz porphyry forms a third phase, probably later than, but possibly of identical origin with, the aplite.

Each phase of igneous activity stimulated the formation of ore deposits. The fissure vein mineralization of the quartz-porphyry phase is, so far as known, restricted to the Butte district. Outside of Butte, 109 veins belonging to the aplite phase have been identified, for which the following characteristics are universal:

1. Position near the contact of the main batholith, with fissures mainly within the granite.
2. Strike approximately east and west.
3. Dip steep.
4. Many parallel and reticulated fissures rather than a single large opening.
5. Extensive replacement of the wall rock by the mineralizing solutions.
6. Sericitic alteration of the wall rock.
7. General presence of the sulphides of all the base minerals—lead, zinc, copper and iron, in all the veins.
8. Predominance of each metal in turn in an orderly succession proceeding from the source of the solutions.
9. Increase in proportion of quartz relative to total sulphides with increased depth.

The approximate east-west strike of these veins is normal to the longer axis of the intrusion and they are regarded as contraction cracks in the outer mile of the cooling granite. The sequence of succession of the minerals of the various veins does not differ with varying proportions of the minerals present. The horizon

[9] *Op. cit.*

of ore precipitation migrates downward through successive stages of mineralization. This relation is well illustrated by Fig. 25 of the paper by Billingsley and Grimes, which further indicates an upward migration of the horizon of ore precipitation following the period of aplite intrusion. Those veins occupying lower horizons have a greater vertical range of mineralization.

The distribution and mineralization of the fissure veins of the Boulder batholith, summarized above, conform with the trend that the cooling curves indicate would result from temperature control of location and zoning of these ores. This, in itself, does not preclude other explanations or make them unavailing, but it does constitute a strong argument supporting the contention that temperature played a dominant part in this case.

GENERAL APPLICATION.

In other localities, the part played by temperature may be less, or its importance may be masked or modified by other factors. However, the cooling sequence indicated by the diagrams, with modifications, is applicable to practically all intrusives. For instance, in the case of igneous activity close to the surface, say at a depth of 1,000 feet, the temperature gradient above the contact will be telescoped or steeper, and remain steeper with continued cooling because of dissipation of heat at and near the surface. The same sized intrusion at a depth of five miles will have a gentler temperature gradient due to the thermal blanket effect of the overlying rock. The size and initial temperature of intrusives also govern the resulting temperature gradient.

In short, the temperature relations that may affect ore deposition are dependent on: (*A*) Initial temperature; (*B*) Size of intrusive; (*C*) Depth of burial; (*D*) Stage of cooling attained when mineralization takes place; (*E*) Rate of advance of these solutions.

A broadly generalized illustration is afforded in the contrast between the gold-ore occurrences of the Canadian Pre-Cambrian shield with those in British Columbia. The following tentative explanation is quoted:[10]

[10] Gold Occurrences in Canada, Summary Account. Geol. Survey of Canada, 1932.

Pre-Cambrian ore bodies are known to have been formed at great depths, probably of the order of 5 or 6 miles, below the then-existing surfaces, and consequently, with the vertical extent of about a mile throughout which the veins have been explored, there was not likely to have been sufficient change in temperatures, pressures or other conditions to produce much change in composition. In the British Columbia deposits, however, the original surface appears to have been not more than 1 or 2 miles above the present surface, and zoning, due to changes in temperature and pressure, as solutions rose, would be much more pronounced.

Zonal distribution is frequently stressed as being vertical, and this is true insofar as batholith roofs are essentially broad and flat, but in some cases, especially with relation to smaller intrusives, the distribution is outward from a focal center, being lateral as well as vertical. The ore veins of Hudson Bay Mountain, British Columbia,[11] show a telescoped lateral zonal distribution, and as one climbs the western slope of this mountain, he passes across a gradation from silver-lead to zinc-copper and then arsenopyrite-pyrrhotite horizons. Actually, in this case, pyrrhotite is at a higher elevation than the lower-temperature minerals, which flank the mountain mass. This is not an example of reversal in sequence of deposition, but merely lateral distribution outward from the core of the mountain, now truncated and exposed by erosion.

VERTICAL RANGE.

A few deposits have been proved to extend to great depths, *e.g.* the Morro Velho, Brazil, vein, now developed for more than 8,000 vertical feet. The striking characteristic of these deposits is their lack of appreciable change in quality. Unfortunately such deposits are rare. Hoover[12] studied several hundred dividend-paying metal mines in various parts of the world, and states:

> Notes were made as far as possible of the depths at which values gave out, and also at which dividends ceased. Although by no means a complete census, the list indicated that not 6 per cent of mines (outside

[11] Jones, R. H. B.: Geology and Ore Deposits of Hudson Bay Mountain, Coast District, B. C. Summ. Rep., 1925, Part A., Geol. Sur. Can.

[12] Hoover, Herbert C.: Principles of Mining, p. 32. McGraw-Hill, 1909.

blanket) that have yielded profits, ever made them from ore won below 2,000 feet. Of mines that paid dividends, 80 per cent. did not show profitable value below 1,500 feet, and a sad majority died above 500. Failures at short depths may be blamed upon secondary enrichment, but the majority that reached below this influence also gave out.

Emmons [13] has shown the relation of the great majority of metalliferous lodes to batholiths, particularly to the rim and outward from the rim.

SMALLER INTRUSIVES.

It has been contended that small intrusives formed near the surface are essentially incapable of producing ore deposits because dissipation of ore minerals would be vastly more probable than effective concentration. The writer appreciates the logic of this argument but believes that exceptions to it may exist. In this case, the importance of temperature is minimized by the necessity for the retention of mineralizers during crystallization of the intrusive, although crystallization would be retarded if the enclosing rocks were heated from the main intrusive from which the sills or dikes are derived, at the time of their injection.

The extreme and least favorable chance for ore concentration is in the case of extrusives where chilling, relief of pressure, escape of gases and loss of mineralizers precludes concentration of ore minerals. This is shown by the lava flows comprising the Columbia plateau of Washington, where many frustrated ore deposits lie disseminated in these flows, which contain an insignificant percentage, but a large quantity, of copper. The Keweenawan flows of the north shore of Lake Superior near Duluth, Minnesota, contain small aggregates and veinlets of fluorite, accompanied by insignificant amounts of copper.

It follows that small intrusives can contain minerals in sufficient quantity to form ore deposits under advantageous circumstances which would permit concentration during crystallization of the molten mass.

In general, of the smaller intrusives, sills appear to be struc-

[13] Emmons, W. H.: Metalliferous Lode Systems and Igneous Intrusives. Trans. Amer. Inst. Min. Eng., vol. LXXIV, pp. 29–70, 1926.

turally more capable than dikes, of producing ore deposits, because the former are more likely to maintain higher pressures as well as retaining the gases and mineralizers which promote deferred crystallization and concentration of the ore minerals.

Dikes commonly show amygdaloidal textures, indicative of loss of pressure during relatively rapid cooling and crystallization. In other cases, differentiation is characteristic of small intrusives. An interesting and informative example of differentiation of a sill about 1,000 feet in thickness is discussed by Emmons,[14] who describes a gradation upward from a pyroxene gabbro into a pegmatitic quartz diorite containing hornblende, and states in part:

> Solutions have been quite active in the sill, as indicated by the altered feldspars and ferromagnesian minerals. This is especially true of the upper part. The presence of a considerable amount of epidote also is indicative of the activity of solutions.
>
> It is possible then to reconstruct a picture of the crystallizing magma, and to gain some idea of the process of differentiation. Intrusion of the sill was followed by a chilling of the lower margin and the formation of the fine-grained rock found there. Any tendency to form a similar fine-grained margin at the top of the sill has been counteracted by the concentration of mineralizers here. The remainder of the intrusive magma, while crystallizing, underwent a slight stratification resulting in an increase in the silica content of the upper part. There is no positive evidence that crystals early to form sank far, but the crystals lower in the sill are more basic than those higher, and micropegmatite is most abundant in the upper part. Having some evidence that the magma was high in solutions, a comparatively simple explanation may be offered. The residual liquor of the magma, formed as crystallization progressed, tended to rise, aided by the mineralizers present. This liquor was, of course, high in silica and alkalies and therefore carried these substances upward with it. Progressively upward, the liquor became more concentrated and crystals in contact with it approached equilibrium with it—hence the *progressively* more sodic feldspars higher in the sill. Also, since it is from this residual liquor that the micropegmatite crystallized later, the micropegmatite too is more abundant higher in the sill.

If the magma from which this sill crystallized had contained

[14] Emmons, R. C.: Diabase Differentiation. Amer. Jour. Sci., (5) vol. XIII, pp. 73–82, 1927.

ore minerals, it might well have been a clear-cut example of small ore bodies genetically related to it.

It is difficult to prove that ore deposits associated with small intrusives have not migrated to their present position from depth, rather than being related in origin to their host rock. Generally this type of deposit never develops into a profitable mine. If these suspected relations could be established during an early stage of development, many fruitless expenditures and blasted hopes could be avoided.

CONCLUSION.

In the foregoing consideration of the manner of cooling of igneous rocks and the possible resulting effects on ore deposition, factors other than temperature have been neglected. This does not mean that the writer considers these other factors unimportant. They have been avoided in order to restrict attention to the thermal sequence resulting from magmatic intrusion. This sequence is believed to be relatively uniform, and variations are largely governed by: (1) initial temperature; (2) size of intrusion; (3) depth of intrusion.

The location or range of any ore deposition dependent on temperature can vary with the rate of advance of ore solutions.

The degree of temperature control of ore precipitation may be affected by other factors to almost any extent, so that no generalized statement of its importance is possible without qualifications.

OLIVER IRON MINING CO.,
DULUTH, MINN.

GENETIC RELATIONS OF SILVER DEPOSITS AND KEWEENAWAN DIABASES IN ONTARIO.

E. S. MOORE.

INTRODUCTION.

It has been recognized since the discovery of silver ore in 1886 in the Lake Superior district of Ontario, that some relation exists between silver deposits and diabase intrusions. Subsequent and more important discoveries of this metal in other parts of the province have increased the evidence of this relationship. Every deposit of silver ore, excepting by-product silver, is closely associated with diabase, generally regarded as Keweenawan in age. Different opinions have been held, however, regarding the source of the silver. Many geologists have contended that the metal has been derived directly from the associated diabase while still hot, and others that it came in as a later phase of the parent magma that gave rise to the diabase.

In view of the lack of unanimity of opinion concerning the source of the silver, the writer undertook a more detailed study of the physical, chemical and petrographical features of the diabases to see whether more data could be obtained that might help to solve the problem of genesis. Through the generosity of the National Research Council of Canada, grants were made to aid field studies and laboratory work on collections of specimens of diabases secured from Cobalt, South Lorrain, Gowganda, Port Arthur, and other areas. These grants being insufficient to complete the investigation, further work has been carried on in the laboratories of the University of Toronto.

Acknowledgments.

The writer acknowledges his indebtedness to the National Research Council of Canada for financial aid allotted for field and laboratory studies. He is indebted to Dr. J. Satterly, Mr. A. M.

Bell and Mr. G. S. MacKenzie, former research assistants at the University of Toronto, for their help with this problem. The petrographic work of Dr. Satterly on the rocks of Cobalt and South Lorrain is deserving of particular mention. He is also grateful to Professor J. T. King, in charge of assaying at Toronto, for his valuable advice and help in testing the diabases for silver. Officials of a number of the mines at Cobalt, and in South Lorrain and Gowganda, kindly extended facilities for securing specimens and studying the formations in their mines, and for their courtesy and aid the writer expresses his sincere thanks. In presenting the results of this investigation the writer desires to be regarded rather as the initiator and director of the study and collaborator of results than as sole claimant to the results of the work done.

DISTRIBUTION OF SILVER DEPOSITS IN ONTARIO.

Silver has been mined in Ontario, in important quantities, mainly in two districts; Cobalt, including several closely related areas such as South Lorrain, Casey township, Gowganda and Elk Lake, and the Port Arthur-Fort William district lying along the northwest shore of Lake Superior (Fig. 1). The Cobalt district is one of the great silver-producing areas of the world, with a total production of about $285,000,000, and has paid dividends of over one-third this amount. The output has fallen greatly in recent years and few mines are now operating. One of these, the Cross Lake mine of M. J. O'Brien Limited, is working under conditions of special interest because the ore is all being obtained from the lower portion of the diabase sill and beneath it in the Keewatin rocks—formations that were at one time generally regarded as unfavorable for the occurrence of ore. High-grade ore has been found in this mine, and it points to the possibility of much silver still reposing beneath the sill. The difficulty in attempting to find it, however, lies in the necessity of doing all prospecting beneath a sill that is normally about 1,000 feet thick. At this particular mine it is only 600 feet thick owing to faulting.

The Port Arthur-Fort William district is of much less im-

portance than Cobalt, but it has had one spectacular mine, Silver Islet, which has yielded about $3,250,000 in silver. This mine was located on a small island only 85 feet in diameter and rising about 10 feet above the level of the lake, 4,000 feet from the mainland. The total production from the district is estimated

FIG. 1. Map of Ontario, showing the location of the chief silver-bearing areas.

at $4,470,000 derived from nine or ten mines. Silver, lead and zinc are distributed throughout an area about 150 miles long by 25 miles wide, but few deposits have so far proved to be of economic importance.

Smaller quantities of silver have been recovered from lead-zinc, copper-nickel and gold ores of the Sudbury, Kirkland Lake, Porcupine and smaller camps. The quantity so recovered commonly amounts to about 1,250,000 ounces per annum.

SPACE RELATIONS OF DIABASE AND SILVER DEPOSITS.

The important silver deposits of Ontario all occur in areas where sills of diabase are found. Although dikes of Nipissing diabase may be numerous, no ore deposits occur where sills are absent. This close association has been regarded by some geologists as due to structural control and by others to a genetic relation.

In the Port Arthur-Fort William district the veins mostly occur along faults in sediments beneath the sills and in the diabase, pointing to structural control as the main feature in the relationship. In the Cobalt district nearly all the ore has come from zones that lie along the upper and lower contacts of the sills and generally extend not over 300 feet from these contacts; a small amount of ore may have come from as great a distance as 1,000 feet beneath the bottom of the sill. As observed by Knight,[1] over 90 per cent. of the silver has come from beneath and from the lower part of the sill at Cobalt, although nearly all the ore from nine mines, including the Beaver, Timiskaming, Nova Scotia and others has been taken from the upper contact. It should be pointed out, however, that the sill has been eroded from the area where most of the mining has been done. Further, the bulk of the silver from Cobalt has been obtained from the sediments of the Cobalt series that formerly were, or are still beneath the sill; a much smaller quantity has come from the Keewatin and the diabase itself. The unequal distribution of silver in the various rocks is attributed to the more ready fracturing of the Cobalt sediments, thus providing more ore channels. Knight has also stated that at Cobalt the contact between the Cobalt series and the Keewatin system has controlled the location of 80 per cent. of the ore and that the ore shoots in the Cobalt series,

[1] Knight, C. W.: Geology of the Mine Workings of Cobalt and South Lorrain Silver Areas. Ont. Dept. of Mines, vol. 31, Pt. 2, p. 7, 1922.

in most of the mines, did not rise more than 100 to 200 feet above the Cobalt-Keewatin contact. There is also a marked tendency for the ore shoots to occur in the Cobalt sediments above troughs in the ancient erosion surface of the Keewatin. These features all point to structural control in the formation of the veins, rather than to chemical control by wall rocks, although at a few places the chemical effects of these rocks seem to have influenced the localization of the ore. Where veins do occur in the Keewatin and diabase, many of them contain very high-grade ore.

At a few of the Cobalt mines, including the two O'Brien mines and the Violet, the ore has all come from the Keewatin and diabase in a zone along the lower contact and within 300 feet of it. The ore shoot in No. 3 vein at the Kerr Lake mine occurred on a fault that reached the middle of the sill or possibly higher. Important upper-contact ore bodies were in the diabase and overlying Keewatin formations. At the Beaver and Timiskaming mines the veins were near a sharp curve in the diabase-Keewatin contact.

In South Lorrain, the commercial ore has practically all come from the upper contact with Keewatin and diabase as wall rocks, although some high grade ore has been found beneath the sill. In Gowganda, nearly all the ore has been found near the upper contact, and the bulk of it in the sill. The veins, although mostly in the upper part of the diabase, are numerous near the center of the sill and on a few properties they occur in the diabase near the lower contact. In the Millerette mine, ore has been worked in the Cobalt conglomerate above the sill.[2]

In the Port Arthur-Fort William district, the relations between the diabase sills and the silver deposits do not appear quite as intimate as at Cobalt. The veins show possibly a greater dependence on faults than those in some parts of the Cobalt district. Geologists who have studied this field have not considered the ores as derived directly from the diabase of the sills.[3]

[2] Burrows, A. G.: Gowganda Silver Area. Ont. Dept. of Mines, vol. 35, Pt. 3, 1926.

[3] Tanton, T. L.: Fort William and Port Arthur, and Thunder Bay Map-Areas, Thunder Bay District, Ontario. Can. Geol. Surv., Mem. 167, 1931.

Innumerable intrusions of Nipissing quartz diabase occur north of Lake Huron. These are mostly dikes but there are bosses and other intrusions, and the diabase at Bruce Mines (a copper mine) may be a sill. The area has yielded little silver, and although some cobalt has been found the silver is associated with small lead and zinc deposits. Copper is widely distributed in veins mostly associated with the diabase intrusions, impregnating and cutting them and the adjacent sediments. Arsenical gold ores occur in the southern part of the area where granite, younger than the diabase, outcrops. There appears to be a relation between the igneous rocks, and the type of ore and gangue minerals in the deposits, the higher-temperature deposits being nearer the granite. The relations of ores and intrusions indicate that the copper, lead, zinc, silver and cobalt were derived from a late and more acid phase of the diabase magma, and the arsenical gold ores from the granite magma which was intruded shortly after the diabase.

DIABASES ASSOCIATED WITH SILVER DEPOSITS.

In the Cobalt district and throughout Ontario, except around Lake Superior, the common diabase contains primary quartz and was called by Miller [4] the Nipissing diabase. It forms sills, particularly at Cobalt, but dikes are the most common type of intrusion. The formation is regarded as Lower Keweenawan in age.[5] At Cobalt and in South Lorrain there is a single sill whose normal thickness is from about 800 feet to 1,100 feet. In Gowganda the main sill is about 1,000 feet, and others range from 50 to 250 feet in thickness; it is possible, however, that there may be only one minor sill that varies in thickness in different places. Burrows has suggested that probably the same great sill occurs in the Cobalt, South Lorrain, Elk Lake and Gowganda areas, but this has never been proven because the masses of diabase in these areas are now separated by erosion.[6]

[4] Miller, W. G.: Notes on the Cobalt Area. Eng. and Min. Jour., pp. 645–649, 1911.

[5] Moore, E. S.: Keweenawan Olivine Diabases of the Canadian Shield. Trans. Roy. Soc. of Canada, Third Series, vol. 23, sec. 4, p. 43, 1929.

[6] Burrows, A. G.: *Op. cit.*

In the Port Arthur-Fort William area, the diabase is more basic than the Nipissing and is younger, probably Middle Keweenawan. The Logan sills, a striking feature of the region, and numerous dikes are composed of this rock.

Nipissing Diabase.—This rock occurs typically in dikes, sills, and other minor intrusions. In the larger intrusions the rock grades into norite and gabbro. It is a dark gray rock of medium grain and ophitic texture. Primary quartz is generally present and most of the larger intrusions have micropegmatite among the finer constituents. In the normal quartz variety, the feldspar is mostly a medium labradorite, in the form of idiomorphic, lath-shaped crystals. In other phases, in sills, the plagioclase may vary from basic labradorite to a medium andesine. The proportion of quartz is small, except where micropegmatite constitutes an appreciable part of the rock or where secondary quartz has been developed or introduced. It is the writer's opinion that in many cases micropegmatite was formed in the diabase through endothermic action, and in some cases by solutions that came from the parent magma, and that it does not always crystallize as an original constituent of the rock.

In his study of the petrography of the sills at Cobalt, South Lorrain, and Gowganda, Satterly recognized four facies of the diabase. In descending order these are: (1) Coarse, gabbroid facies; (2) hybrid facies; (3) quartz norite; and (4) quartz diabase. The thickness of the different types of rock varies greatly; their character changes from point to point; and all the facies may not be present in every section of a sill.

The following mineral analyses by Satterly show the composition of some of the facies. The analyses are of volume, and were made by using a slight modification of Johannsen's method.[7] The slide is mounted on the stage in the usual way, the microscope being turned into the horizontal position. The image of the field is reflected by a plane mirror at a 45° angle upon a sheet of paper, and a pencil sketch made. The areas of the minerals are determined by using an Ansler planimeter. Five fields are usually taken, in some cases ten, and with the coarse-grained types

[7] Johannsen, A.: Jour. Geol., vol. 27, pp. 276–285, 1919.

Mineral Analyses of Facies of the Diabase.

	Specimen No. S. L. 60.	No. S. L. 10.	No. C. 69.
Quartz diabases:			
Plagioclase	45.6%	49.9	48.9
Augite	45.0	46.5	46.8
Quartz and micropegmatite	6.5	2.6	2.9
Ilmenite	2.4	0.8	1.1
Biotite	0.5	0.2	0.3
	100.0%	100.0	100.0

	C. 31.	C. 33.	C. 64.	S. L. 4.	S. L. 6.	S. L. 8.	G. 11.	Average of Nine Analyses.
Quartz norites:								
Plagioclase	51.7	47.9	58.4	48.8	56.3	46.6	55.0	51.2
Pyroxene [8]	45.2	46.4	39.5	48.7	39.7	48.3	40.0	44.9
Quartz and micropegmatite	1.7	1.4	0.9	0.6	1.9	2.6	2.0	1.7
Ilmenite	0.9	1.7	0.5	0.9	1.2	1.5	1.8	1.2
Biotite	0.5	2.6	0.7	1.0	0.9	1.0	1.2	1.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[8] The orthorhombic pyroxene, which is chiefly enstatite, is included with the augite. It forms about 20% of the pyroxene, and from 5 to 20% of the rock. Nineteen determinations gave an average of 9.5% in the rock.

Hybrid Facies.		*Coarse, Gabbroid Facies.*	
	C. 72.	C. 67.	G. 16.
Plagioclase	48.5	41.5	54.7
Augite and hornblende	44.1	33.5	32.6
Quartz and micropegmatite	6.5	21.4	7.8
Ilmenite	0.2	3.6	3.4
Biotite	0.7	0.0	1.4
Pyrite		0.0	0.1
	100.0	100.0	100.0

Specimens marked C. are from Cobalt; S. L., from South Lorrain; and G., from Gowganda.

the whole of the field is measured. This method proved a little more satisfactory than the Johannsen method for measuring rocks with ophitic texture because it was easier to keep track of the minerals that had been measured.

The main differences in the types are: A slight increase in acidity in the feldspar toward the top of the sill, a greater proportion of micropegmatite in the gabbroid and hybrid facies, and a much larger proportion of hornblende, after augite, in these two facies. The hybrid facies, although not always recognizable, is characterized by heterogeneous texture and a mixture of minerals differing from that in the other part of the sill. There are pink spots of micropegmatite, patches of plagioclase and black pyroxene, considerable hornblende, and irregular stringers and blotches of coarse material consisting of dark green augite and greenish white feldspar. It shows a high degree of alteration of the ferromagnesian constituents, giving the impression that the type is due to hydrothermal alteration (possibly endothermic) rather than to differentiation in the sill.

Olivine occurs in many sections, and in one taken from the 500-foot level of the Silver Leaf mine at Cobalt it formed over 27 per cent. of the rock. Many sections show apparent remnants of olivine crystals, outlined in iron oxide and serpentine, surrounded by enstatite. Some of these sections contain quartz, an association which suggests that much of the quartz, which can not be readily distinguished from primary quartz, was introduced into the sill by hot solutions.

The presence of norite in the sills in the different parts of the Cobalt silver district, in the Onaping area to the west and in the Sudbury nickel field, south of the Onaping area, suggests a genetic relation between the Nipissing diabase and the Sudbury nickel intrusive.

Section across the Cobalt Sill.

The writer collected a series of eight samples of the diabase across the sill at Cobalt. The section (*A B*, Fig. 2) lies between the Nipissing and Nova Scotia properties near the northeast end of Peterson lake. The samples were analysed by Mr. G. S. MacKenzie and the results are given in Table I.

Table I indicates no evidence of marked differentiation in the sill where the specimens were taken. There is an increase in

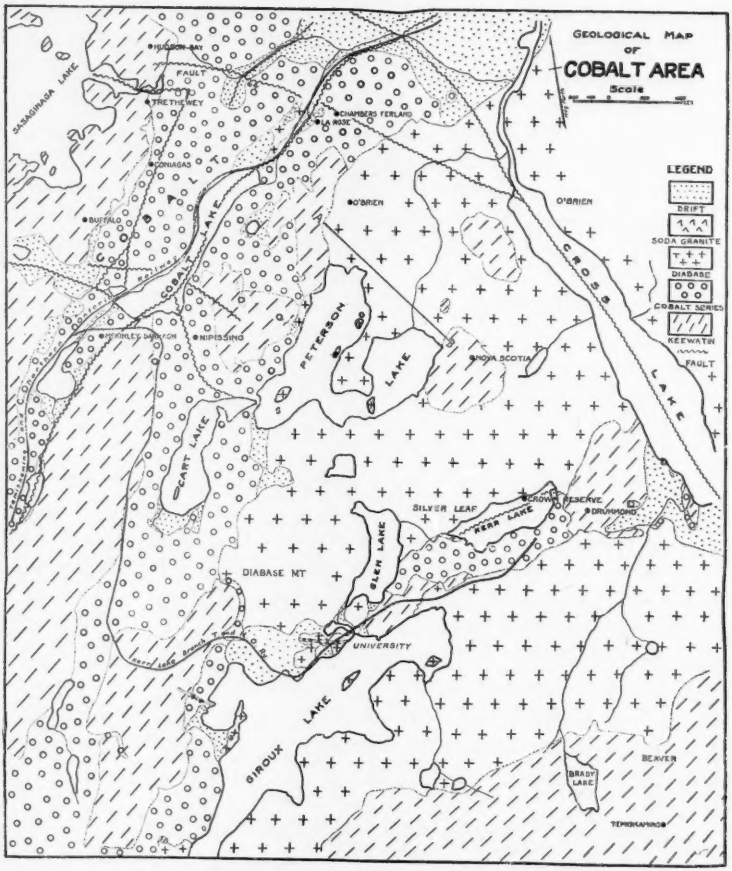

FIG. 2. Compiled from maps by Miller and Knight, Ontario Department of Mines. Major faults are indicated.

femic constituents near the center but silica remains remarkably constant throughout, and the alkali content, although lower in the central portion, is similar near the base and top.

Macroscopically, the specimens show little variation in charac-

TABLE I.

ANALYSES OF SPECIMENS FROM NIPISSING DIABASE SILL AT COBALT.

Oxides.	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	50.63	49.20	50.27	49.28	50.48	50.58	50.01	50.32
Al_2O_3	12.68	14.19	15.02	16.30	17.12	16.20	16.15	14.75
FeO	10.17	11.89	9.19	8.71	8.28	8.69	9.99	11.73
Fe_2O_3	1.79	.95	.96	.86	.37	.31	.31	.56
MgO	8.01	7.86	9.17	9.29	9.44	9.30	9.02	6.82
CaO	10.52	10.73	12.37	12.00	12.21	12.25	12.23	10.45
Na_2O	1.96			1.28	2.82			3.67
K_2O	1.71			1.48				
TiO_2	1.07	.91	.74	.64	.58	.61	.69	1.22
Total	98.54			99.84	101.30			99.52
Spec. Grav.	3.0144	2.9748	2.9418	3.0144	2.9794	3.0042	3.0326	3.0048

Total distance across the sill on line of section approximately 1,175 yards. No. 1 taken 5 feet above diabase-Keewatin contact: 1–2, 77 yds., 2–3, 210 yds., 3–4, 137 yds., 4–5, 176 yds., 5–6, 220 yds., 6–7, 198 yds., 7–8, 154 yds. No. 8 taken about 10 feet below top of sill. Sill estimated at about 1,000 feet in thickness with dip of 30–45° southeastward.

ter, except for somewhat coarser texture in the upper part of the sill. Specimen No. 8 contains indefinite patches of light and dark material up to a few inches in diameter. The lighter patches have a coarse texture and consist chiefly of plagioclase with a few crystals of augite.

In thin sections the feldspar is quite fresh, except near the top of the sill, which shows considerable evidence of hydrothermal alteration. The pyroxenes are augite and enstatite, the former predominating. Enstatite is present in all specimens except No. 8; it is more abundant near the center of the sill than near the top or bottom. No olivine was found but there is evidence of olivine having been present in some of the enstatite near the center of the sill.

Diabase of the Port Arthur-Fort William District.—The diabase in this district occurs in dikes, and in sills that range from 2 to several hundred feet in thickness. The tops of many of the thick sills have been eroded and although the diabase masses are unconnected, it is possible that most of the silver deposits are associated with what was originally one large sill. The dikes are mostly 10 to 50 feet wide, but Tanton records an unusual

thickness of 650 feet.[9] Some dikes served as feeders for the sills; others cut them.

The diabase rarely contains primary quartz, and olivine is prevalent in many sections. Hypersthene is fairly abundant in some sections of the sills, but on the whole orthorhombic pyroxene is not so common here as in the Cobalt diabase. At Silver Mountain, magnetite, in peculiar needle-like crystals, is abundant in the highly altered basal portion of the sill, and its occurrence points to the strong effect of hydrothermal solutions on this part of the intrusion. As at Cobalt, there is in most places some increase in the proportion of feldspar toward the top of the sill. Patches of anorthositic rock 10 feet or more in diameter have been observed in the upper part of thick sills. On the whole, the rock shows a tendency to become a little more gabbro-like in the upper portion of the intrusion but there is not much evidence of differentiation.

SODA GRANITE, APLITE, GRANOPHYRE AND "RED ROCK."

In the Cobalt district, particularly in the Gowganda and Elk Lake areas, there are many narrow dikes of aplite and some bodies of what has been described as soda granite. There are also, both in this and the Port Arthur-Fort William district, numerous occurrences of a pink to red rock associated with diabase intrusions. This is known in the field as "red rock," syenite, and more correctly as granophyre. It consists chiefly of acid plagioclase, in places in graphic intergrowth with quartz, although quartz may be absent. There are varying proportions of mica, titanite, black iron oxide, pyrite, and chalcopyrite, and chlorite is commonly present. It grades into the diabase, particularly the gabbroid facies, and occurs as blotches and specks and also as a filling in the interstices between the feldspar and other crystals. Where the diabase is in contact with sediments there is also a gradation into these rocks. At one place the granophyre occurs as an irregular mass up to 30 feet in thickness and several hundred feet in diameter, along the upper contact of a sill in the Gowganda area. It may also form irregular tabular bodies, and at the University mine at Cobalt there is a dike-like mass of what

[9] *Op cit.*, p. 66.

has been called soda granite that has been traced at intervals for about 800 feet along the strike; it reaches 50 feet in width. It is similar in composition to some of the aplites in the Elk Lake area.

The aplite dikes are mostly fairly clear-cut bodies in the upper part of the diabase sills, commonly not over three or four feet in width. They cut the granophyre, but at some places there is evidence of a gradation between the two. The aplite shows a graphic intergrowth of quartz and feldspar which in some cases is practically pure albite. Calcite is a common constituent and gives the impression of having crystallized with the quartz and feldspar as a primary mineral, in some cases at least. Titanite and sulphides, such as chalcopyrite and pyrite, are also commonly found in these dikes.

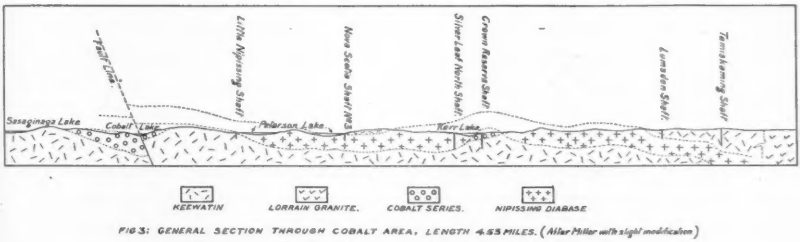

FIG 3: GENERAL SECTION THROUGH COBALT AREA, LENGTH 4.5 MILES. (After Miller with slight modification)

FIG. 3. General section through Cobalt area.

In the Port Arthur-Fort William district granophyre occurs at a number of points along the upper side of diabase sills and inclined dikes in contact with sediments, and the rock is similar in most respects to that in the Cobalt district. Detailed descriptions of the nature and composition of the granophyre and aplite of the two districts have been given by Collins,[10] Bowen,[11] Hore[12] and Tanton.[13]

[10] Collins, W. H.: The Quartz-Diabase of Nipissing District, Ontario. ECON. GEOL., vol. 5, pp. 538–550, 1910.

[11] Bowen, N. L.: Diabase and Granophyre of the Gowganda Lake District, Ontario. Jour. Geol., vol. 18, pp. 658–674, 1910.

[12] Hore, R. E.: Diabase of the Cobalt District, Ontario. Jour. Geol., vol. 18, pp. 271–278, 1910. Differentiation Products in Quartz Diabase Masses of the Silver Fields of Nipissing, Ontario. ECON. GEOL., vol. 6, pp. 51–59, 1911.

[13] Tanton, T. L.: *Op. cit.*, pp. 71–75.

Collins considers that these special types of rock are facies of the diabase magma and he states that there are only two petrographic species; diabase and aplite. The normal quartz diabase is the undifferentiated phase and the aplite is regarded as a differentiate from the diabase magma. Between these extremes are gabbroid diabase, slightly more acid than normal diabase, micropegmatite, and granophyre. The calcite in the aplite dikes is considered as having been derived from an outside source, probably Keewatin rocks in the neighborhood of the sill. Collins presents a strong case for differentiation. He submits analyses of the various rocks to sustain his contention that all these types of rock could have been derived from the diabase magma by a process of differentiation. In a later work [14] he goes further, and states that the metallic contents of the silver veins are the final products of differentiation within the sill.

Bowen regarded the granophyre as the result of heated soda-bearing waters acting on the diabase and sediments where in contact with each other, the process being similar to that producing adinole in other regions. The solutions supplied the soda and the sediments, alumina and silica, to form the "red rocks." Carbonate waters are assumed to have been present to provide the calcite so commonly found, and the aplite was formed by the more aqueous residuum of the granophyre solutions. It is also suggested that this aqueous residuum probably deposited the valuable metallic content of the aplites and the associated calcite veins.

The writer is left in some uncertainty as to Bowen's conclusions regarding the source of the alkali waters. In discussing the origin of the granophyre he remarks that the granophyre "solution" was foreign to the diabase magma, as indicated by the intense alteration of the diabase, and he adds that, "Although admitting that the separation of the soda-bearing carbonate waters from the magma is a sort of differentiation, in itself it is not sufficient to produce granophyre but only to contribute to its formation by inducing alteration of the slaty sediments." [15]

[14] Collins, W. H.: The Geology of the Gowganda Mining Division. Can. Geol Surv. Mem. 33, p. 105, 1913.

[15] Bowen, N. L.: *Op. cit.*, p. 670.

Hore attacks the conclusions of Collins and Bowen as to the origin of the granophyre and aplite. He states that granophyre is found at many places in the diabase where there is no evidence that sediments were present to aid in its formation. Further, he supplies analyses of diabase, sediments, and soda granite from the Cobalt area to show that there are no chemical relations among these rocks that indicate the possibility of the formation of granophyre by alteration of the sediments and diabase. He concludes that granophyre is the result of alteration of the diabase through the action of solutions derived from the diabase, as the result of differentiation, and that the irregular dike or vein-like bodies are of the nature of "contemporaneous veins." He objects to Collins' conception of the unmixing of a micropegmatite and diabase magma. He believes also that the ore minerals are the end phase of the differentiation in the diabase sill.

Burrows [16] states that in the vicinity of Lost Lake there is certainly strong evidence of "red rock" being formed by contact assimilation, since in places it is difficult, if not impossible, to define the boundaries of the intrusive and the quartzitic sediments. At another place he states that the aplite is considered a differentiate of the diabase and a number of the mineral veins are aplitic. Commonly the aplite grades into the diabase along the walls, and some veins show aplite next to the walls, followed by a layer of crystallized quartz, with crystals extending into the calcite that occupies the center of the vein.[17] He concludes that the relations of diabase, aplite, and quartz indicate differentiation, and the calcite and ore minerals have come in later, probably from the same source.

Tanton describes a number of occurrences of granophyre in the Port Arthur-Fort William district connected with the upper contacts of sills and inclined dikes. It is stated that in some zones the granophyre grades on one side through quartz diabase into diabase and on the other through rocks which are commonly mottled, nodular and spotted, into unaltered sediments.[18] In all

[16] Burrows, A. G.: *Op. cit.*, p. 15.

[17] *Idem*, p. 23.

[18] Tanton, T. L.: *Op. cit.*, p. 72.

cases where the occurrence of granophyre has been observed, it occurs along a contact between diabase and sedimentary rock, and Tanton suggests that the granophyre is the result of interaction between the country rock and an agent from the intrusive. Since this type of rock is found on the upper side of sills and inclined dikes, it indicates that the altering agent tended to rise and escape from the intrusive. Analyses of diabase, slate, and granophyre from Pyritic Island show that soda, sulphur, and carbon dioxide are each more abundant in the granophyre than in the shale or the diabase.[19] Further, the drusy character of some of the rock suggests that volatile constituents from the intrusive were responsible for the formation of this special type of rock.

The question of whether these acid rocks are direct differentiates of the diabase sills has a bearing on the subject of this paper. From the descriptions given it is evident that, in some localities at least, the granophyre unquestionably results from the action of waters from the diabase intrusions on sedimentary rocks. It may be observed also that in the Cobalt district the granophyre and aplite are most extensively developed in those areas where sediments of the Cobalt series are widespread and not where the diabase is directly in contact with the Keewatin rocks. They are most abundantly developed on the upper side of sills and inclined dikes, apparently favoring the hypothesis of differentiation as their source; but, as Bowen has pointed out, the Foot Lake sill in the Gowganda area is only 50 feet thick, and it shows insufficient differentiation to account for the formation of the large mass of granophyre. There is too little evidence of differentiation in the dikes of the Port Arthur-Fort William area to account for its formation there. A study of the chemical composition of the sill at Cobalt indicates that if there is any tendency to develop a more acid zone in the sill it is found near the upper part. It might, therefore, be assumed that these acid differentiates would be drawn from this portion of the sill to form the aplites. As Bowen has suggested, however, it seems improbable that these solutions would so intensely alter the diabase itself.

[19] *Idem*, p. 75.

The writer believes that the field conditions suggest that the solutions which formed the granophyre and aplite rose along or through the intrusion from the parent magma. There is considerable micropegmatite in places in the diabase, and if it were assumed that the solutions that formed the micropegmatite also gave rise to the granophyre and aplite, one might expect to find this imprisoned as zones in the magma at points where it was unable to escape upon cooling of the mass. Such does not seem to be the case on any appreciable scale.

The aplite dikes have some features of pegmatites but, as is well known, pegmatites are rare with rocks as basic as the Nipissing diabase. Hess states:[20] "Pegmatites accompanying the more basic rocks, especially rocks as basic as the amphibolites, pyroxenites and gabbros, are rare." A review of the chemical analyses of the diabase sills of the Cobalt district shows that the rock is even more basic, in spite of the presence of some quartz, than many gabbros and diabases. The pegmatites in basic rocks usually show a mineralogical composition differing considerably from that of the aplites under discussion.

The writer does not argue that a basic magma, if of sufficient volume, could not differentiate so as to give rise to a more acid phase than the original magma, and even form aplitic bodies. There are many cases where somewhat similar rocks occur in large bodies of the Nipissing diabase in Ontario, and although assimilation of other rocks may account for many of them, it is difficult to assign all of them to this source. In this region, however, it seems that Bowen's explanation for the origin of the granophyre, and probably the aplite, may better fit the conditions. It is probable that the diabase sills would give off, in the closing stages of cooling, solutions rich in soda that could, by reaction with some foreign rock, produce the granophyre and aplite. The mineral associations of the calcite and sulphides in the aplite dikes, when considered in the light of our present knowledge of extensive replacement in pegmatites, raise the question as to whether these may not be due to replacement in the dikes at a later period than the deposition of the quartz and feldspar.

[20] Hess, Frank L.: Pegmatites. Econ. Geol., vol. 28, p. 448, 1933.

FAULTING IN THE SILVER-PRODUCING DISTRICTS.

Miller [21] recognized during his early work in the Cobalt camp that several periods of faulting on a large scale had occurred in the region west of Lake Timiskaming. Some of the faults were pre-Cobalt but others cut the diabase sill and were occupied by silver ores. Still later faults, post-Niagaran in age, run through the Lake Timiskaming basin and adjacent areas. In a later work, Knight [22] has given a full account of the faults in the Cobalt and South Lorrain areas, the largest of which are thrust faults, from the southeast, with displacements up to 550 feet. Some small normal faults at Cobalt, for example, No. 64, carried important veins, but none of the major fractures carry ore for a large part of their length. Many veins follow faults of small displacement. Post-ore movement has occurred on the Cobalt Lake and a few other faults in this area and in the mines at Gowganda.

In connection with the distribution of ore at Cobalt it is interesting to observe that little ore has been found in the area north of fault No. 64, which may be a branch of the Cross Lake fault. This fault may have acted as a barrier to the movement of ore-bearing solutions toward that area.

In South Lorrain one fault and its branches have been responsible for most of the ore. This is the Woods vein fault, of thrust type with a displacement of about 30 feet. It cuts the diabase sill, and Boydell [23] has pointed out that some of the faults that cut the diabase follow previously existing faults that have been followed by Haileyburian lamprophyre dikes.

In Gowganda, according to Campbell,[24] many of the ore-bearing faults lie in the upper part of the diabase sill, although several have been found in the center and a few well down toward the bottom. In some of the mines the sill shows, according to

[21] Miller, W. G.: The Cobalt-Nickel Arsenides and Silver Deposits of Timiskaming. Ont. Bur. of Mines, vol. 19, pt. 2, 1913, and earlier editions.

[22] Knight, C. W.: *Op. cit.*

[23] Boydell, H. C.: Geological Structure Disclosed in the Keeley Mine. Can. Min. and Met. Bull. 230, pp. 726–750, 1931.

[24] Campbell, A. D.: Gowganda Silver Area. Can. Min. and Met. Bull. 216, pp. 453–470, 1930.

Burrows,[25] a striking vertical-columnar jointing with columns 10 to 15 feet in diameter. Veins commonly swing around these columns in following the enlarged fractures.

A special feature of the Gowganda area is the presence, as recognized by Burrows, of quartz-diabase dikes that cut the olivine diabase sill. The exact relationships of these dikes and the veins are indeterminable, but they are of interest as indicating the continuance of injections of Nipissing diabase in this area after the sill had solidified sufficiently to chill the edges of these intrusions. There are also in this area large calcite veins that contain little or no ore and in some cases cut the ore-bearing veins.

In the Port Arthur-Fort William region, according to Tanton,[26] faulting localized the intrusion of many of the dikes. Subsequent faults of small displacement[27] cut the intrusions and localized the ores. Faulting seems to have produced practically all the channels in which the veins were formed, and the ores were derived, not directly from the diabase, but from the deeper-seated parent magma of the sills.

THE SILVER VEINS.

The veins of the Cobalt district are characterized by small size and great richness. The width of the majority of the workable veins is in inches rather than in feet, and few exceed 1,000 feet in length. Many of them occur along faults, a few on the large faults, but most of them along the smaller ones and associated fractures of lesser magnitude. There were many veins, of great importance in the aggregate, that occupied small fractures, in some cases even joint cracks that show no displacement. Sheets and leaves of native silver with little or no gangue have been found in mere cracks in the diabase. Some veins have fairly distinct walls, but replacement of wall rocks is a characteristic feature at many points. In the Gowganda and Elk Lake areas a few veins follow aplite dikes. These have been described as consisting of aplite zones along the walls followed by quartz, then calcite, with ore minerals in the calcite.

[25] *Op. cit.*, p. 19.

[26] *Op. cit.*, p. 75.

[27] On Silver Islet the displacement may be as much as 300 feet.

Carbonates are the most characteristic gangue minerals, calcite being the common carbonate with dolomite as a minor constituent. Quartz is fairly common, and a little fluorite and barite have been observed. The most typical ore minerals are cobalt-nickel arsenides and sulphides, and native silver. A large number of minerals has been listed by Knight [28] and several species have since been added to his list. Nearly all the native silver is regarded as primary but an outstanding example of secondary silver described by Bell [29] was found in the Woods vein in South Lorrain. In this vein, pre-Glacial oxidation extended far below the surface and greatly enriched the ore at a depth of 420 feet.

The type of mineralization found in the Cobalt camp is in most respects common to the other silver areas of this district. In Gowganda chalcopyrite, sphalerite, pyrite and specularite are much more abundant than at Cobalt. In the Lake Superior region the mineralization differs in many respects from that at Cobalt. Although cobalt, nickel, arsenic, antimony, bismuth, and mercury all occur in the veins, as at Cobalt, they are of much less relative importance. Native silver occurs in much smaller proportion, and Tanton [30] regards this mineral as secondary except for most of the Silver Islet ore. Argentite is much more widespread and important than at Cobalt, and such minerals as galena, sphalerite, pyrite and chalcopyrite, which occur in relatively small quantities at Cobalt, are common constituents of the veins in this district. The veins here are larger; simple veins reach 70 feet in width and vein systems, consisting of a number of closely spaced veins, may have a width of 100 feet. The gangue minerals are chiefly calcite, dolomite, quartz, fluorite, and barite.

Paragenesis and Zoning of Minerals.

Those who have studied the vein minerals of Cobalt agree regarding most of the major features of paragenesis. Miller [31]

[28] *Op. cit.*, p. 35.

[29] Bell, J. M.: Deep-seated Oxidation and Secondary Enrichment at the Keeley Silver Mine. Econ. Geol., vol. 18, pp. 684–694, 1923.

[30] *Op. cit.*, pp. 90–91 and 97.

[31] *Op. cit.*, Ont. Bur. of Mines, vol. 19, Pt. 2, p. 10.

early established the following order: (1) Smaltite, niccolite and dolomite; (2) Fracturing and reopening of veins; (3) Rich silver ores and calcite; and (4) Decomposition products. Campbell and Knight,[32] from more detailed work, arranged the following series: (1) Smaltite, (2) Niccolite, (3) Period of movement and fracturing, (4) Calcite, (5) Argentite, (6) Native silver, (7) Native bismuth, (8) Period of decomposition, (9) Erythrite and annabergite. Several writers have recognized that smaltite is much less abundant than was formerly thought to be the case. A more elaborate classification of these minerals has recently been published by Thomson,[33] as follows: (1) Arsenides and sulphides, (2) Calcite, followed by fracturing, (3) Native silver, dyscrasite, argentite, native bismuth, bismuthinite, cosalite, and later calcite, (4) Sulphides of lead, zinc, copper, pyrrhotite, marcasite, tetrahedrite and quartz, (5) Sulpho-salts such as pyrargyrite, proustite, stephanite, and later silver, and (6) Decomposition products. This arrangement is similar to that advanced by Ellsworth [34] in an earlier publication.

At the Frontier mine in South Lorrain, Bastin [35] found that native silver is contemporaneously intercrystallized with niccolite, one of the first minerals formed. Most of the silver, however, is late primary, and occurs together with calcite, tetrahedrite, chalcopyrite, sphalerite and bismuthinite in veinlet-like masses that traverse the commoner metallic minerals and are clearly the last portion of the ore to crystallize.

Todd,[36] in describing the paragenesis of the minerals in the veins of the Gowganda area, concluded that native silver was one of the earliest minerals to be deposited and that its deposition

[32] Campbell, W. and Knight, C. W.: A Microscopic Examination of the Cobalt-Nickel Arsenides and Silver Deposits of Timiskaming. ECON. GEOL., vol. 1, pp. 767–776, 1906.

[33] Thomson, Ellis: A Qualitative and Quantitative Determination of the Ores of Cobalt, Ontario. ECON. GEOL., vol. 25, pp. 470–505, 627–652, 1930.

[34] Ellsworth, H. V.: A Study of Certain Minerals from Cobalt, Ontario. Ont. Bur. of Mines, vol. 25, Pt. 1, 1916.

[35] Report quoted by Knight, *op. cit.*, p. 352.

[36] Todd, E. W.: Gowganda Vein Minerals. Ont. Dept. of Mines, vol. 35, Pt. 3, p. 78, 1926.

continued to a late stage. Contemporaneous deposition of silver, arsenides and gangue minerals occurred in this field.

In offering an explanation for the colloform structure in the arsenides, Lindgren [37] suggests that they are gel-replacements of earlier minerals. He states: "The veins are generally considered as mesothermal, that is, formed at intermediate temperatures, probably not exceeding 250° C. At Cobalt the deposition may be divided into three stages: (1) The filling of the fissures by crystalline calcite and dolomite; (2) the replacement of the carbonates by gels of arsenides and sulpharsenides; and (3) the introduction, mainly by replacement, of crystalloid native silver."

The order of deposition apparently has not been quite the same in all areas, even though the same or similar minerals have been deposited. A summation of the paragenesis yields few features of value in attempting to solve the source of the metals. The veins are so small and shallow that there is little hope of finding much evidence of zoning. Knight,[38] however, observes that the minerals in some of the faults are different from those in the joint-plane veins. In the fault veins, galena, zinc blende, chalcopyrite, pyrite, marcasite, quartz and calcite occur in small quantities and apparently preceded silver and the cobalt-nickel arsenides. This conclusion seems to conflict with that reached by Thomson. The occurrence of pyrrhotite, mentioned by Thomson as a fairly late mineral, but usually regarded as a high-temperature mineral, is of interest. Although not abundant, it seems to be restricted to the O'Brien mines, whose workings lie in the lower part of the diabase sill and beneath it. In these mines, and especially in the Cross Lake mine, arsenopyrite is an important mineral in proportion to the cobalt-nickel arsenides. Sphalerite and galena are also considerably more abundant, judging from Thomson's figures,[39] than in most other mines. Chalcopyrite appears to be much more uniformly distributed through-

[37] Lindgren, Waldemar: Metasomatism. Bull. Geol. Soc. of Amer., vol. 36, p. 260, 1925.

[38] *Op. cit.*, p. 17.

[39] *Op. cit.*, p. 642.

out the camp than the other sulphides mentioned. Further, the sulphides of copper, zinc, and lead show a tendency to increase in proportion in the deeper mine workings in the camp, and a little gold is reported from the deeper levels of the Kerr Lake mine.

The association of pyrrhotite, arsenopyrite and sphalerite in the O'Brien mines, which are farther down the dip, on the lower side of the sill, and nearer the Cross Lake fault than the other mines, suggests that solutions depositing them may have risen along the faults from a magma source lying beneath these properties.

As previously mentioned, there occurs north of Lake Huron a group of deposits containing gold, copper, lead, zinc, silver and cobalt and showing genetic relationships with Nipissing diabase and granite intrusions, the latter being a little later in age than the former.[40] The conditions in this area have some bearing on those in the Cobalt district, since there is here a rough zoning, with arsenical gold ores closely associated with the granites, and those of the other metals, with diabase intrusions. There is evidence of decreasing temperature for deposition of copper, lead-zinc and cobalt deposits. There is no evidence of important deposits being derived directly from the diabase itself, but those of the different metals seem to have all been derived from a common magma. Further, Knight has suggested that the veins at Bruce Mines occur in a sill of Nipissing diabase.[41] These veins distinctly cut the sill as other veins cut the dikes of diabase.

In the silver deposits of the Port Arthur-Fort William district there is little evidence of zoning.

ORIGIN OF THE SILVER DEPOSITS.

Experience has shown that the relations between silver deposits and diabase intrusions in Ontario are so close that no prospector can safely ignore them. Further, the occurrence of ore and

[40] Moore, E. S.: Ore Deposits near the North Shore of Lake Huron. Ont. Dept. of Mines, vol. 38, Pt. 7, 1929.

[41] Knight, C. W.: The North Shore of Lake Huron. Ont. Bur. of Mines, vol. 24, Pt. 1, p. 238, 1915.

diabase sills seems to be inseparably linked in the areas where important deposits have been found. There are, however, other factors of great importance in connection with the occurrence of the silver ores, of which faulting is the most important. Faulting seems to have been a dominant factor in the development of commercial deposits in many sections of the silver fields. Knight's map [42] shows a striking distribution of the majority of the producing veins in zones along the major lines of faulting in the Cobalt camp. Faults have also played an equally important rôle in the other silver camps. Other features of importance are the physical character of the rock formations, their ability to fracture, and their relations to one another, as for example, the relations of the sediments of the Cobalt series to the diabase sill and the underlying Keewatin schists and greenstones. Deformation of the sills or deflections in their contacts also seem to have played a part in concentrating ore-bearing solutions in certain sections of the contact zones, as in the Timiskaming and Beaver mines at Cobalt and the mines in the Gowganda area.

Source of the Metals.—The hypotheses advanced to account for the source of the metals in the veins may be divided into four groups: (1) The diabase sills supplied the ore and gangue minerals by processes of differentiation and vein-wall alteration; (2) the sills furnished the metallic contents of the veins by differentiation, and the Keewatin and other formations the carbonate and barite gangue; (3) the contents of the veins came from a deep-seated source in the parent magma from which the diabase erupted; and (4) the minerals were derived from the diabase sills or the surrounding rocks through leaching of these rocks by ground waters.

The last hypothesis may be dismissed at once. As for the others, some geologists have strongly supported (1) and (2) and others have as vigorously supported (3).

Barlow [43] early expressed the opinion that the silver veins were closely related to the aplites, which he called diabase-pegmatites,

[42] Sheet 31a–20, Ont. Dept. of Mines, vol. 31, Pt. 2, 1922.

[43] Barlow, A. E.: The Origin of the Silver of James Township, Montreal River. Jour. Can. Min. Inst., vol. 11, pp. 256–273, 1908.

and that the metals came from the diabase sill by differentiation. Tyrrell [44] apparently held similar views and has been quoted as so doing, but in one place he speaks of mineral-bearing solutions ascending from the heated interior of the earth to make the veins. Hore [45] has been a champion of the hypothesis that the sill was the source of the metals and has also emphasized the importance of the Keewatin greenstones as an influence in ore deposition and as a source of the calcite gangue. Collins [46] has contended that the aplite and granophyre represent acid differentiates of the sills and that the ore minerals were derived from the same source. He regarded the Keewatin rocks as the probable source of the calcite, and the Laurentian rocks as the source of the barite gangue, which he states is found only in areas where there are veins of this mineral in the Laurentian formations that lie beneath the diabase sill. Bowen [47] apparently considered the sill to be the source of the metals through differentiation. In speaking of the solutions that formed the aplite, he says: "This aqueous residuum probably deposited also the valuable metallic content of the aplite veins and of the associated calcite veins." Whitman [48] advanced the hypothesis that the metals were derived from the diabase by diffusion and metasomatic fixation. He makes some statements, however, not in accord with those of others when he speaks of no ore bodies being found in major fissures. He also suggests that the rough sequence of deposition seems to be calcite, cobalt and nickel arsenides, and silver. Lindgren has fairly recently added his opinion to those favoring the diabase

[44] Tyrrell, J. B.: Mineral Veins in the Montreal River District. Can. Min. Jour., vol. 2, pp. 651a–652a, 1908. Vein Formation at Cobalt, Ontario. Can. Min. Jour., vol. 1, pp. 301–303, 1907.

[45] Hore, R. E.: Origin of Cobalt-Silver Ores of Northern Ontario. Jour. Can. Min. Inst., vol. 11, pp. 275–286, 1908. Differentiation Products in Quartz Diabase Masses of the Silver Fields of Nipissing, Ontario. Econ. Geol., vol. 6, pp. 51–59, 1911.

[46] Collins, W. H.: The Geology of Gowganda Mining Division. Can. Geol. Surv. Mem. 33, 1913. The Quartz Diabases of Nipissing District, Ontario. Econ. Geol., vol. 5, pp. 538–550, 1910.

[47] *Op. cit.*, p. 669.

[48] Whitman, A. R.: Diffusion in Vein-Genesis at Cobalt. Econ. Geol., vol. 15, pp. 136–149, 1920.

as the source of the ore minerals, when he says: "The second stage consisted in the introduction of mobile solutions emanating from the cooling diabase. They may have been more or less mixed with water of magmatic or meteoric origin"; and: "I believe the silver also came from the diabase magma, but in this reaction, as far as known, no colloidal processes were involved." [49]

Miller [50] studied the Cobalt area as few men have, and he was always somewhat cautious in expressing his opinion regarding the source of the silver. He remarks that the metals may have come up from considerable depth with the waters, or they may have been leached out of what are now the folded and disturbed greenstones and other rocks of the Keewatin. He published several editions of his report on the camp and in the final report [51] he makes the following statement:

> However, the widespread occurrence of cobalt veins in the diabase or in close association with it, shown by discoveries during the last seven or eight years, throughout a region three thousand square miles or more in extent, appears to be pretty conclusive proof that the diabase and the ores came from one and the same magma.

A note is appended that the waters depositing the metals are regarded as representing the end product of the eruption. Whitehead [52] considered that the solutions did not come from the diabase sill but rose from a deep-seated source, and that the concentration of ore near the Keewatin-Cobalt contact was due to this being the first contact met in their ascent. He further considered that the veins were predominantly due to replacement and the major fractures of economic importance were formed in definite relation to faults and folds. Reid [53] and Boydell [54] express quite definite opinions that the ores did not come from the diabase sill but from the magma common to both diabase and ore.

[49] *Op. cit.*, pp. 260–61.

[50] *Op. cit.* Ont. Bur. of Mines, vol. 19, Pt. 2, p. 8.

[51] *Idem.*

[52] Whitehead, W. L.: The Veins of Cobalt, Ontario. Econ. Geol., vol. 15, pp. 103–135, 1920.

[53] Reid, J. A.: Silver Deposition and Enrichment at Cobalt, Ontario. Econ. Geol., vol. 13, pp. 385–392, 1918.

[54] Boydell, H. C.: *Op. cit.*, p. 748.

Silver in the Diabase.—In view of the many ideas expressed regarding the source of the metals, it was decided to test the diabase for silver. The object of the tests was to determine whether the diabase carries appreciable quantities of silver and whether there appears to be any concentration of silver in any particular section of the sill.

Difficulties arise in attempting to determine the presence of minute quantities of silver in a rock. It was fully realized when the work was undertaken that one could not hope to obtain absolute determinations, but it was believed that approximate values and relative quantities might be of some interest in a study of the origin of the ores. In considering a method, two were suggested, the spectroscopic and the fire assay. Although the former method had been used successfully in determining small quantities of certain elements in rocks, it was found that it could not be used satisfactorily to determine such small quantities of silver as might be expected and were later found in the diabase. The fire assay was finally decided upon as the best method available, although it is open to the objection that litharge always contains some silver even when a "silver-free" brand is used. Further, there is always considerable loss of silver in cupelling the buttons.

The first series of tests was made by Satterly with the aid of Professor J. T. King, who kindly placed the facilities of the Assay Laboratory of the University at our disposal, and gave us the benefit of his long and valuable experience in assaying. The method employed consisted in running ten 30-gram crucibles, combining the buttons into two lots of five each, and scorifying until buttons of suitable size were obtained. These were then cupelled in one and one-quarter inch cupels. The resultant beads weighed and divided by 5 gave the silver content of the rock plus that of the flux. The litharge used in the flux was carefully assayed after the same manner as the rock and a reduction made for its silver content. The silver in the flux varied in different batches but in every case the silver beads obtained, when the rock was added to the flux, weighed more than when the flux alone was assayed, showing that there was sufficient silver in

the diabase to be measured. The results indicated that the relative proportions of silver were probably not far from correct.

A series of tests was run on samples of barren rock, that is, rock near which there was no ore, taken from No. 8 winze through the sill on the Frontier mine, South Lorrain. The results are shown in Table II.

TABLE II.

Spec. No.	Depth from Surface.	Silver Content.
S 29.....	600 feet (7th level)	0.031 ozs. per ton
S 31.....	675 "	0.023 " " "
S 32.....	750 "	0.016 " " "
S 34.....	900 "	0.030 " " "
S 36.....	1050 "	0.027 " " "
S 39.....	1275 "	0.013 " " "

Average 0.023 ozs. per ton, or 0.000079 per cent.

No. S 29 was taken about 200 feet below the upper contact of the sill, and S 39 at 100 feet above the lower contact.

Another method of assaying suggested by Professor King was later used by Bell on specimens from Cobalt, Gowganda, Rouyn, and the Port Arthur-Fort William district. This method, known as the iron-nail method, was found on experiment to give more constant results than the method used by Satterly in the first tests. Fresh litharge, the most nearly "silver-free" that it was possible to obtain, was procured from the Denver Fire Clay Company and was carefully assayed. The results were found to be very nearly constant at 0.0235 ounces per ton. It was tested by the use of potassium bitartrate and an iron nail, with satisfactory results. By using 12.5 A.T. (assay ton) in the litharge test and 5 A.T. in the rock assay, the size of the bead was kept nearly constant. The loss in cupelling is estimated to run about 10 per cent., because a curve shows that there is an increase in the loss of silver in cupelling with a decrease in the quantity of silver present in the charge. The figures quoted should, therefore, be increased by probably 10 per cent. to arrive at a truer conception of the silver present in the diabase.

The assays of specimens from the Cobalt district were made on different phases of the diabase in an effort to determine whether the silver content varied appreciably with the changes in the rock of the sill. The following are the results:

TABLE III.

Spec. No.	Locality.	Type of Rock.	Silver Content.
			Ozs. per ton
1.	Silver Leaf mine, Cobalt, 80 feet from lower contact	Quartz diabase	0.047
2.	Silver Leaf mine, Cobalt, 350 feet from lower contact	Quartz norite	0.032
3.	Gowganda	Quartz norite	0.025
4.	Combination of specimens from sill near Kerr lake, Cobalt	Quartz norite	0.031
5.	Gowganda	Hybrid type, coarse grained	0.031
6.	Castle Trethewey mine, Gowganda, about 500 feet below upper contact	Quartz gabbro	0.039
7.	Silver Leaf mine, Cobalt, 60 feet below upper contact	Quartz gabbro	0.044

Average 0.036 ounces per ton, or 0.00012 per cent.

An assay of a composite sample taken across the sill near the Beaver mine, Cobalt area, omitting the lower, more altered portion of the sill, gave 0.019 ounces of silver per ton.

A sample from the diabase sill at the Shuniah mine, just north of Port Arthur, gave 0.0185 ounces, and a composite sample from several dikes of the "older gabbro" of the Rouyn district, Quebec, a rock similar in composition to the Nipissing diabase, gave a considerably lower silver assay of 0.008 ounces.

The results of the assays of the diabases are regarded as a fairly good indication of their silver content and especially of the relative content of the different phases. It is evident that the diabase magma contained silver in all the areas where silver deposits have been found, and the writer believes that if the Nipissing diabase were assayed it would be found to have a low content of silver in most, if not all areas, whether silver deposits are present or not. The figures obtained from the assays, in both sets of tests, indicate a relatively low silver content in the quartz-norite phase of the sill and a higher one in the quartz gabbro. This may be explained as due to the fact that in the field the gabbroid phase shows greater alteration, as a rule, than the noritic phase, and it is probable that some silver has been introduced into it by solutions that were responsible for the

alteration of the rock. This conclusion is strengthened by the fact that the silver contact is equally high in some of the quartz diabase which has not undergone differentiation, but being near the bottom of the sill it has usually suffered considerable alteration by thermal waters.

In connection with the occurrence of metals in the diabase it may be added that three analyses of the diabase at Cobalt showing nickel and cobalt are mentioned by Hore.[55] These show 0.04, 0.11, and 0.01 per cent. NiO and CoO for the diabase from the University, Silver Bar, and Kerr Lake mines respectively. Collins [56] states, however, that neither these metals nor barium and strontium could be detected in the diabase of the Gowganda area.

SUMMARY AND CONCLUSIONS.

The close association of silver-cobalt-nickel ores and diabase intrusions in Ontario has been fully established, and further, it has been shown that the occurrence of ores of this type in commercial quantities is restricted to those areas in which diabase occurs as sills or sheet-like intrusions. Many areas in which similar diabase occurs in dikes do not have commercial silver deposits. The nature of the ore deposits, the replacement of wall rocks, and the relations of the deposits to igneous intrusions, leave no doubt of their hydrothermal origin and their derivation from similar magmas. The silver content of the diabase indicates that the parent magma contained this metal, and it is incredible that it could have been collected in the ore deposits in such quantities and under such conditions as it has been found by any process of leaching of the diabase and adjacent rocks by ground waters.

Admitting that the source of the metals was in the diabase magma, there remains the question as to whether they were derived directly from the sills by differentiation or whether they came to the deposits from a deeper source in the parent magma, where they were concentrated by differentiation. The writer concludes, from the petrographic, structural and other features of

[55] Econ. Geol., vol. 6, pp. 51–59, Table I, 1911.
[56] Econ. Geol., vol. 5, p. 549, 1910.

the various silver-bearing areas, that the source of the silver for most of the ore was in the parent magma and not in the sills. The rôle played by the sills in the emplacement of the deposits is regarded as largely a structural one. The extent of the differentiation in the sills has not been sufficient, in the writer's opinion, to produce the bulk of the ore. The presence of aplite and granophyre with the diabase in some localities indicates that soda-rich solutions escaped from the diabase sills, but whether they originated in the sills or in the parent magma has not been proven. It is possible that some of the metal content of the veins may have been carried out of the diabase in these alkaline waters, but it remains for those who believe that this is the source for the ores to show that there are any space relations between the aplites and the ore deposits when all the silver-bearing areas are considered. The aplites commonly occur in the upper part of the sills, and the great bulk of the ore in the Cobalt district has come from beneath the sill.

The writer sees serious difficulties in applying Whitman's diffusion hypothesis to the Cobalt district. It has been shown beyond question that large faults cut the sill before ore deposition occurred; solidification must, therefore, have proceeded to such a point that no liquid rock could flow out of any part of the sill into these fractures. The different stages in vein formation and the replacement of the wall rocks are difficult to account for satisfactorily on this basis where a solid sill is involved.

If the ore solutions came from the magma reservoir, they could rise along the larger faults and the sill contacts, where most of the deposits are found. Post-sill faults are found in all camps, and at Cobalt there is a remarkable distribution of veins in zones along either side of the Cobalt Lake, Kerr Lake, and other faults. Further, fault No. 64, lying to the north of the Cobalt Lake fault, seems to have acted as a barrier to the movement of ore-bearing solutions in that direction. It is difficult to see how it would have had this effect if the solutions came down from overlying diabase beyond this fault. The location of such a large proportion of the silver ore in the Cobalt area near the Keewatin-Cobalt contact also favors the idea that the solutions

came from below. In the Port Arthur-Fort William area the veins are mostly in faults that cut the sediments beneath the sill and extend up into the sill. Tanton [57] does not question as to whether the solutions ascended from a deeper-lying magma source to form these deposits, since such a source is believed to be the only one possible.

The association of certain minerals such as chalcopyrite, pyrite, sphalerite, and galena with faults in the Cobalt area, the presence of pyrrhotite, and the relative increase in arsenopyrite down the dip of the sill on the lower side near a large fault, support the opinion that the solutions came up from a deeper source—the parent magma of the diabase.

Finally, it is believed that the magma from which the silver ores of the Cobalt district were deposited underlay a large section of northern Ontario at the beginning of Keweenawan time. Vast eruptions of magma occurred, taking the form of dikes in most areas but of sills where Cobalt and other sediments were present to affect their form. Around Lake Superior the eruptions with which the silver ores are connected are probably Middle Keweenawan in age; but there are many similarities in the conditions there and in the Cobalt district. The sills acted as guides for the solutions that arose from the parent magma and as caps for impounding the solutions. They also played an important rôle in developing fractures because of their great mass and their relatively competent character when subject to thrusts. The difference in the composition of the gangue and ore minerals in the Cobalt, Lake Huron and Lake Superior districts may be explained as due in part to the degree to which the acidity in the parent magma had developed, and in part to the nearness of acid intrusions that followed the injection of the diabase. In a few places, a portion of the series of deposits made by the solutions that escaped from the parent magma may have been removed by erosion, leaving only the higher temperature veins.

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TORONTO, ONT.

[57] *Op. cit.*

MAGNETITE CEMENTING CERTAIN ORE CONGLOMERATES OF THE MESABI RANGE.[1]

JOHN W. GRUNER.

UNUSUAL magnetite occurrences have been observed in the upper layers of two ore bodies of the central Mesabi range in Minnesota. The two deposits, one at the Kinney pit, the other at the Brunt pit, are about seven miles apart. The latter occurrence was called to my attention by Mr. W. P. Wolff, mining engineer at Ely, Minnesota, when I mentioned to him the occurrence at the Kinney mine.

The magnetite from Kinney is almost theoretically pure, as seen in the following analysis made by Dr. R. B. Ellestad.[2]

		Theoretical composition
FeO	30.94	31.03
Fe_2O_3	69.05	68.97
Mn	trace	——
	99.99	100.00

Search through the literature on magnetite shows this occurrence to be the purest ever analyzed. The very slight excess of Fe_2O_3 is present as minute veinlets of hematite visible in polished sections with high magnification.

The magnetite is found as vein and cavity fillings in an "ore conglomerate." It is either massive or in crystals. The latter are mostly octahedrons, although the dodecahedrons may be strongly developed. Striated crystals are common. The sizes of the crystals vary greatly. Some are as large as two inches in diameter; many measure from ¼ to ½ inch across. They are

[1] Presented before the Society of Economic Geologists, Chicago Meeting, Dec., 1933.

[2] Total iron and ferrous iron were determined by electrometric titration with dichromate. The samples dissolved readily in HCl, leaving no visible residue. In the FeO determination the solution and titration of the sample were carried out in a CO_2 atmosphere. The Mn test was made by the usual periodate method.

sufficiently numerous not to be considered mineralogical curiosities. None of the material tested is lodestone. It has a high luster for magnetite and commonly occurs with somewhat nodular pyrite, which probably was marcasite originally. This pyrite was contemporaneous with the magnetite, as is evidenced by the growth of pyrite on magnetite and magnetite on pyrite. Ferruginous carbonate (siderite or dolomite) in small flat rhombohedrons is found on both minerals.

The iron-ore conglomerate in which these minerals are found overlies the typical Mesabi "trough" ore bodies. It may reach a thickness of 40 feet and more, though commonly it is thinner. As far as can be ascertained it is not found anywhere outside the boundaries of the trough ore bodies. The two particular bodies under consideration are above the "intermediate paint rock" of the Biwabik formation. They extend high up into the Upper Slaty Division. If an angular unconformity exists between the conglomerate and the bedded ore, it is inconspicuous.

The conglomerate consists of pebbles, which are mostly subangular and are unsorted. They range from sand grain sizes to those of cobble stones. They are relatively soft and now are all iron oxide or hydroxide. They are cemented mostly by fine-grained hematite or limonite. The latter may be exceedingly hard and dense, presumably because of being a chemical precipitate in the conglomerate. In exceptional cases, magnetite may be the cement between small pebbles.

This conglomerate probably has nothing in common with the ore conglomerate that grades upward into Cretaceous shale and, therefore, is thought to be Cretaceous in age.[3] This Cretaceous conglomerate is made up chiefly of hard, polished, limonite pebbles derived from secondary limonite of the ore bodies, and is cemented mostly by soft shaly material. The pebbles can easily be freed from this matrix.

Credit for recognizing two ore conglomerates on the Mesabi range belongs to Mr. J. F. Wolff, of the Oliver Iron Mining Company, who conveyed his ideas to the writer before the mag-

[3] Gruner, J. W.: Contributions to the Geology of the Mesabi Range. Minn. Geol. Survey Bull. 19, p. 7, 1924.

netite was found. So far, the two conglomerates have not been found superimposed anywhere on the range.

Since the magnetite, particularly the large crystals, appears to be of hydrothermal origin, the age of the conglomerate containing it is of importance. If it had formed *after* the ore had been concentrated by the leaching of SiO_2 from the iron formation, a number of facts are not easily explained:

1. How could relatively soft iron-oxide pebbles persist without being ground up to fine material during sedimentation?

2. Much secondary oxide of iron forms a cement between the pebbles and this oxide is clearly a chemical precipitate and not detrital. Nothing of this sort is found in the Cretaceous conglomerate. This chemical movement of the iron oxide is very similar to that which occurred in the ore bodies proper during the removal of the silica.

3. No pebbles of any rock occur in the conglomerate.

4. Why does the conglomerate not extend beyond the "ore troughs" if it was formed on a post-ore erosion surface?

These questions can be answered if we believe the conglomerate to have developed in the following way. After deposition of the Biwabik formation and the conformable Virginia slate, slight tilting and erosion exposed the iron formation in a general outline more or less similar to the present exposures on the producing range. A conglomerate of pebbles of iron formation accumulated in places on the iron formation. About this time leaching by hot waters began from below and ultimately also leached the pebbles of their silica. Some of the iron which was moved upward in this process was redeposited as oxides among the pebbles and in other places. During and after the leaching, slumping displaced stratigraphically higher beds, including the conglomerate, to lower positions. It removed them in this manner from topographically higher position which later suffered erosion to the level of the present peneplain. Only by such an unusual sequence of events could such an unusual conglomerate be preserved. It is probable that systematic search will reveal more of these conglomerates and magnetites with such an interesting paragenesis.

It will be noticed that these occurrences support to a certain extent the contentions of the writer that secondary concentration of the Lake Superior iron ores was produced by the action of hot water.[4] Magnetite has usually been considered a mineral not produced by meteoric waters. Even if it may be shown that certain black marine chemical precipitates contain magnetic oxide, still that would not imply that crystals of the dimensions described above could form from meteoric solutions.

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[4] Gruner, J. W.: Additional Notes on Secondary Concentration of Lake Superior Iron Ores. ECON. GEOL., vol. 27, pp. 189–205, 1932.

BARITE DEPOSITS OF THE SINKS DISTRICT, BIBB COUNTY, ALABAMA.

WALTER B. JONES AND T. N. McVAY.

In 1875, Eugene Allen Smith reported[1] the existence of barite at the "Sinks" on Six Mile Creek. Recently, much exploratory work has been carried out which has disclosed some interesting information.

This district is located some ten miles northeast of Centerville, in the northeast corner of Bibb County. The area has long been known as the Sinks, from a large number of sink holes in the region. Most of the known barite deposits of the district are in adjacent parts of Township 24 North, Ranges 10 and 11 East. The nearest rail shipping point is Piper, six miles away.

The districtly is gently rolling to rugged, with an average difference in elevation of about 100 feet. Most of the region is heavily covered with hardwoods and scattered pines. It is drained by Six Mile Creek and Little Cahaba River.

GEOLOGY.

The Sinks is in a sharply folded and faulted zone of Paleozoic rocks just above the fall-line of the Mississippi Embayment. It is immediately south of the Cahaba Coal field, from which it is separated by a major fault. The region surrounding the barite deposits is also faulted. (Fig. 1.)

Origin.—An extended discussion of the origin of barite, concerning which much has been published, is out of place in this brief note. However, the occurrence of fluorite as incrustations on, as well as intimately associated with the barite, is regarded as supporting the hydrothermal theory of origin. Several of the test pits in the Sinks district proper show fluorite in amounts varying from a trace to approximately 2 per cent. The existence of veins, stringers, and masses of barite in unweathered, appar-

[1] Report of Progress for 1875, Ala. Geol. Survey, p. 85.

ently non-shattered limestone, certainly signifies replacement, but does not clarify the method or methods by which such replacement was accomplished. Apparently the fluorite and barite were formed at or about the same time. The mineralized solutions quite evidently traveled along fault or bedding planes. The formation was by the crystallization of barium sulphate, present in dilute solutions which followed such fissures.

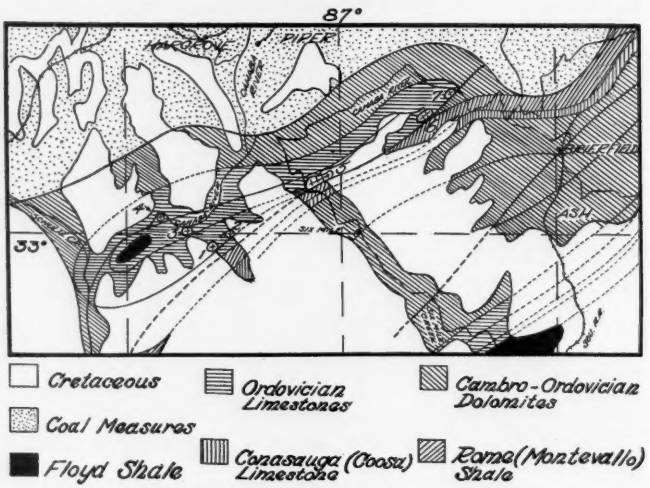

FIG. 1. Sketch map showing the geology and barite deposits of the "Sinks" district, Bibb County, Alabama.

Some of the barite crystals that formed in cavities were large, attaining two to three inches in length. It might be postulated from Von Weimarn's theory [2] that the supersaturated solutions were exceedingly dilute, ranging from N/20,000 to N/7,000. Since this is the concentration given for $BaSO_4$ present where large crystals are formed, the time of precipitation is given as several years. This is merely a suggestion, since there is little available data as to the rate of growth of crystals formed from slightly soluble compounds in natural processes.

[2] Ware, Chemistry of the Colloidal State, p. 173.

The type section is as follows:

System	*Formation*	*Description*	*Thickness*
Cretaceous	Tuscaloosa	Sand, gravel and clays	0–50′
Ordovician	Little Oak Limestone	Dark, thick-bedded, coarsely crystalline limestone	300′
	Lenoir	Dark, finely crystalline, low-magnesian limestone	500′
	Mosheim	Thin-bedded, abundantly fossiliferous limestone	100′
	Newala	Almost entirely massive-bedded limestone	1000′
	Longview	Mostly cherty limestone, in part dolomite	500′
Cambro-Ordovician	Chepultepec	Chert-bearing dolomite, limestone near bottom	1000′
	Copper Ridge	Light gray, siliceous to cherty dolomite	2000′
	Bibb	Coarse-grained, highly siliceous dolomite	400′
	Brierfield	Thick-bedded, blue, siliceous dolomite.	1500′
Cambrian	Conasauga	Dark limestone and occasional shale members	500′
	Rome (Montevallo)	Red shale and rusty-colored calcareous sandstone	2000′

It will be observed from Fig. 1 and the above section, that most of the Cambro-Ordovician formations are faulted out, bringing the barite-bearing Ordovician limestones into juxtaposition with the Rome formation, of Cambrian age. It is significant that the majority of barite deposits of Alabama are in Ordovician limestones.

In the northeast section, the fault dips approximately 65° SE., with the Rome (Montevallo) shale resting on the limestone and its residual soil in which the barite occurs. One test pit went through 30 feet of shale and then encountered barite-bearing clay at what was considered the fault plane. In the rest of the area, the faults are not so evident.

BARITE.

Occurrence.—The barite occurs along the fault that separates the Rome or Montevallo shales from Ordovician limestones. In

the northeast part of the area, the mineralized zone is in or near the fault plane, and to the southwest the barite zones widen out for a maximum distance of several hundred feet from the fault. It is possible that there may be additional minor faults in this part of the field. It appears that most of the deposits are in the Newala formation, although the Fancher seems to be in the Mosheim formation. One of the most interesting features of the deposit is the existence of masses of barite in unweathered limestone, commonly in considerable quantity. This undoubtedly accounts for the unusual concentration of the ore in residual soil over portions of the area.

Associated Minerals.—The barite, mostly white in color, occurs in veins and in other cavities in the limestone. The contacts between the limestone and barite are in most cases sharp, with no alteration of the limestone. However, in some places the limestone has been altered, is colored green by chlorite, and contains small crystals of fluorite.

Fluorite is also associated with barite in some of the samples, but is segregated. Where fluorite is present, it occurs in veins, as fairly large crystals in the barite, or at the contact between the barite and the limestone. Calcite crystals are also associated with the barite in places. A few cavities in the barite contain small crystals of sulphur.

With the exception of limonite, no other accessory minerals in addition to fluorite, calcite and native sulphur, were found associated with the barite.

Samples taken from the Fancher property (No. 6) are gray in color. However, these samples became white in color when roasted at red heat.

INDIVIDUAL DEPOSITS.

1. *B. A. Cotes* (NW. ¼ S. 3) and *H. H. Cotes* (NE. ¼ S. 4, T. 23 N., R. 10 E.).—This occurrence is probably in the Newala Limestone. There has been a small amount of prospecting, and some barite was shipped from this place in 1917–18. The reserves are not known.

2. *May Johnston* (SE. ¼ S. 34, T. 24 N., R. 10 E.).—This locality was noted by McCalley,[3] and some barite was dug out of the head of a small branch and shipped in 1917–18. No data regarding reserves are available. It appears to be in the Newala Limestone.

3. *Walton Pratt* (*Pratt Ferry*) (S. 33, T. 24 N., R. 10 E.).—Barite here has been known for many years, and the large masses on the surface are particularly characteristic. The occurrence is evidently in the Mosheim formation.

4. *Mrs. Julia Wallace* (SW. ¼ of SE. ¼, S. 29, T. 24 N., R. 10 E.).—This locality is also known as River Bend, and the barite occurs as irregular veins and masses in the Newala Limestone.

5. *Sinks Proper* (Sections 24, 25, and 36, T. 24 N., R. 10 E., and S. 30, T. 24 N., R. 11 E.).—This deposit evidently is in the Newala Limestone, and averages 400 feet wide and about 4500 feet long. The depth of weathering averages 15 feet. The estimated yield, according to evidence gathered from about one hundred test pits and trenches, will be one half ton per cubic yard, or 300,000 tons. In several of the test pits, each yard of residual soil produced as high as three tons of barite. The color is white to light gray, and the barite is of high quality.

6. *Julian Fancher* (SE. ¼ of SE. ¼, S. 17, T. 24 N., R. 11 E.).—The occurrence here appears to be in the Mosheim formation, although the exposures are too poor for accurate determination. At this place, eighteen test pits have been dug, in an area 100 feet wide and 300 feet long. The deepest pit is 43 feet, which did not reach the bottom of the weathered zone. Barite continued to and in the bottom of this pit. From the large quantity of barite near the fault plane, it is likely that this place can be successfully mined, even after unweathered rocks are encountered. The barite exceeds one half ton per cubic yard of dirt at this place, but there has not been sufficient prospecting on which to base accurate estimates of reserves.

7. *Maguire Shoals* (NW. ¼ S. 16, T. 24 N., R. 11 E.).—Barite has been frequently reported from this place, but there has

[3] Coosa Valley Report, Ala. Geol. Survey, 1897, p. 493.

been no prospecting nor production. It apparently occurs in the Newala Limestone.

CONCLUSION.

This group of deposits is regarded by the writers as having distinct commercial aspects, both from the quality and quantity of the ore. The average barite content in the residual soil is much higher than in other Alabama deposits which have been operated in the past. There is no apparent reason why these deposits should not be profitably mined.

GEOLOGICAL SURVEY OF ALABAMA,
UNIVERSITY, ALA.

KAOLINITE IN ILLINOIS COAL.[1]

CLAYTON G. BALL.

INTRODUCTION.

PETROGRAPHIC investigation of the identity, character, distribution, and abundance of mineral constituents in Illinois coals has been undertaken by the Illinois State Geological Survey in order to provide information on mineral matter in coal, and because such data are necessary to stratigraphic, physical, microbotanical, and beneficiation investigations now in progress.

Concentration of mineral constituents of Illinois coals for petrographic analysis was effected by separating the "float" and "sink" fractions of finely ground coal in separatory funnels, using a liquid of 1.70 specific gravity as the separating medium. By examination of the "sink" portions of samples from successive levels in coal No. 6 from Franklin County, vertical variation in abundance and composition of the mineral matter was established for a complete column of this coal. During the investigation it was found that a large proportion of the separable mineral matter was composed of three minerals—calcite, pyrite, and a hydrated aluminum-silicate mineral identified as kaolinite.

Since the occurrence of kaolinite in coal is not well known and has not been described in detail, it appears desirable to present an account of its occurrence and physical character and the data on which its identification is based.

OCCURRENCE AND PHYSICAL CHARACTERISTICS OF KAOLINITE.

Kaolinite occurs in places in the more conspicuous cleat joints of such coals as the Grape Creek bed near Danville, Illinois, where it is found in joints that extend through various thicknesses of the bed. In coal No. 6 in Franklin County, kaolinite

[1] Published with the permission of the Chief, Illinois State Geological Survey, Urbana, Illinois. Presented before the American Mineralogical Society, December, 1933.

occurs both in the vertical desiccation cracks in vitrain (anthraxylon) bands and in the cavities in bands and lenses of fusain (mineral charcoal).

Desiccation cracks in Illinois coals are commonly restricted to bands of vitrain, although where several of these occur close together the cracks may break across the intervening clarain

FIG. 1. Polished section of coal, showing mineral-filled desiccation cracks. Natural size.

(attritus). Vertical dimensions of these cracks vary according to the thickness of the vitrain bands, ranging from less than a millimeter to 1½ or 2 centimeters. In width the cracks range from 0.05 to more than 1.0 mm. with an average width of less than 0.5 mm. In horizontal sections the cracks commonly form a rough pattern developed by two intersecting systems of fracture,

one commonly better developed than the other. The lines of desiccation may be less than one, or as much as 4 or 5 cm. apart, dividing the vitrain bands into square or diamond-shaped blocks. The appearance of kaolinite-filled desiccation cracks in a polished section cut at right angles to the bedding is illustrated in Fig. 1.

The kaolinite in the desiccation cracks is opaque, white in color, with porcellaneous luster. Under the microscope it is found to be entirely crystalline, although crystal form is not apparent. The crystals are commonly elongated transversely to the margin of a veinlet, but mostly extend only part way towards the center, the interior part being filled with unoriented grains. Diameters of the unoriented grains vary from .001 to .020 mm., while the average diameter of oriented grains is .005 mm.

Kaolinite may entirely fill a desiccation crack but it is more generally associated with calcite, which occurs as a thin film on one or both sides of the kaolinite. In certain parts of coal No. 6, particularly below the "blue band," a characteristic widespread clay parting in that coal, calcite is the prominent mineral constituent in the desiccation cracks. For the entire bed, however, the average content of kaolinite is considerably greater than that of calcite. If associated with even minor amounts of calcite, the kaolinite may appear to effervesce, a fact that has hitherto doubtlessly contributed to the confusion in its identification.

In a few parts of the bed, initial filling of a desiccation crack with kaolinite or calcite has evidently been followed by renewed desiccation, since two, or even three, distinct veinlets of the mineral may occur side by side in a single crack.

Kaolinite, as has been stated, occurs also in the cavities of fusain. Fusain is an important lithologic ingredient of Illinois coals, occurring as widespread thin bands, as lenticles, and as individual particles, and appears to be the only banded ingredient of coal that possesses porous structure after coalification. Kaolinite in fusain assumes the shapes of the cavities which, when the containing walls are broken away, appear as narrow, elongated cylinders. The cavity fillings are too small to be visible without magnification, the average diameter being less than 0.1

mm. Cylinders of kaolinite are occasionally found in resin rodlets, such cylinders having diameters from two to five times that of the cylinders in fusain. The average diameter of the individual grains composing the cylinders in fusain and resin is less than .010 mm.

The minerals kaolinite and calcite, and to a greater or lesser extent pyrite, occur as secondary deposits in those channelways within the coal that were accessible to aqueous solutions. Although the coal substance in itself is relatively impermeable, solutions may circulate along faults, joints, and desiccation cracks, and along permeable bands or lenses. Secondary mineral deposition in coal commonly occurs in these places.

IDENTIFICATION OF KAOLINITE.

Identification of the kaolinite is based on its optical properties, chemical analysis, dehydration curve, and X-ray diffraction pattern.

Optical Properties.—Indices of refraction and birefringence of eight samples of kaolinite taken from various levels in the coal bed are listed in Table I. Other optical constants could not be measured because of the small size of the constituent grains.

TABLE I.

REFRACTIVE INDICES OF KAOLINITE.

Location.	α.	γ.	$\gamma - \alpha$.
256.5 cm. above floor[a]	1.560	1.565	.005
230.2 " " " [a]	1.560	1.565	.005
172.9 " " " [a]	1.560	1.566	.006
102.7 " " " [a]	1.561	1.565	.004
98.7 " " " [a]	1.560	1.565	.005
56.5 " " " [a]	1.560	1.566	.006
26.1 " " " [a]	1.560	1.565	.005
21.7 " " " [a]	1.560	1.564	.004
Near Pontiac, S. C.[b]	1.553	1.560	.007
Saline County, Ark.[c]	1.562	1.568	.006

[a] Kaolinite from coal No. 6, Franklin County, Illinois.

[b] Kaolinite from Sand Hill station, near Pontiac, S. C. (Ross and Kerr: U. S. Geol. Survey, Prof. Paper 165–E, 1931, p. 162.)

[c] Kaclinite from Globe bauxite mine, near Bauxite, Saline County, Ark. (Ross and Kerr: U. S. Geol. Survey, Prof. Paper 165–E, 1931, p. 162.)

Analogous optical constants for two type kaolinites representing the range of optical constants in the kaolinite group, as given by Ross and Kerr,[2] are included. The optical constants of the kaolinite in coal agree closely with those listed for typical kaolinites.

Chemical Analysis.—A small sample of the clay mineral was picked from the coal by hand for chemical determination and

TABLE II

CHEMICAL ANALYSES OF KAOLINITE.

	1	2	3	4
SiO_2	43.80	43.78	45.56	46.60
Al_2O_3	39.36	40.06	37.65	39.49
Fe_2O_3	.82	.64	1.35	—
MgO	.16	.16	.07	—
CaO	1.17	.36	.10	—
Loss on ignition	15.40	15.10	14.42	13.91
	100.71	100.10	100.61 *	100.00
$SiO_2 : Al_2O_3$	188 : 100	185 : 100	202 : 100	200 : 100

1. Kaolinite from Illinois coal. Dr. O. W. Rees, analyst, Illinois State Geological Survey.

2. Kaolinite in vermicular grains from kaolin seams in bauxite, Saline County, Ark. F. A. Gonyer, analyst, U. S. Geological Survey Professional Paper 165–E, 1931, p. 163.

3. Kaolinite from Sand Hill station, near Pontiac, S. C. F. A. Gonyer, analyst, U. S. Geol. Survey Prof. Paper 165–E, 1931, p. 163.

4. Theoretical composition of kaolinite with formula $2H_2O.Al_2O_3.2SiO_2$.

* Includes traces of K_2O, Na_2O and TiO_2.

dehydration data. Only clean white fragments, as free as possible from other matter, were chosen for analysis so as to avoid including altered or oxidized material. The analyzed kaolinite is compared with the two type kaolinites having the highest and lowest silica-alumina ratio as given by Ross and Kerr,[3] and with the theoretical composition of pure kaolinite of the formula $2H_2O.Al_2O_3.2SiO_2$, in Table II. The chemical composition of the clay mineral from its coal is found to agree with that of the

[2] Ross, C. S., and Kerr, P. F.: The Kaolin Minerals. U. S. Geol. Survey Prof. Paper 165–E, 1931, p. 162.

[3] Ross, C. S., and Kerr, P. F.: *Op. cit.*, p. 163.

kaolinite group, although loss on ignition is slightly higher than in any of the analyses heretofore published. This may be due to inclusion of small amounts of organic matter in the hand-picked sample.

Dehydration Curve.—The amount of water loss at temperature intervals from 110° to 1000° C. is given in Table III. Loss of

TABLE III.

DEHYDRATION OF KAOLINITE.

Temperature Degrees C.	Moisture Loss Per Cent. *A.*	*B.*
110	.26	.30
160		.42
200	.55	
250	.54	.42
300	1.21	.51
350	1.47	.78
400	1.59	
410		1.05
450	1.60	1.50
485	6.18	1.98
500	7.91	
525		12.93
550	13.61	
560		13.38
600	14.47	13.71
650	14.77	
700	15.12	
750	15.40	
950 to 1000	15.40	14.73

A. Kaolinite from Illinois Coal. Dr. O. W. Rees, analyst, Illinois State Geological Survey.

B. Kaolinite from Pontiac, S. C. (Ross and Kerr: U. S. Geol. Survey, Prof. Paper 165–E, 1931, p. 166.)

water (vertical) is plotted against temperature (horizontal) to give the dehydration curve shown in Fig. 2. Two significant points on dehydration curves of clay minerals are those where the very rapid loss of water begins and ends. For the clay mineral in coal the water loss is gradual up to a little over 450°, where rapid loss begins and the curve steepens sharply. This continues to between 550° and 600°, where the rate of loss diminishes strongly, the curve flattening out markedly, but rising slowly to the point where dehydration is complete at 750°. The behavior of this mineral upon dehydration is similar to that of

type kaolinites, where rapid loss begins between 390° and 485° and ends between 525° and 600°, as shown by Ross and Kerr.[4] The shape of the dehydration curve of the clay mineral in coal is sufficiently similar to curves of type kaolinites (Fig. 2) and sufficiently different from the distinctive curves of other clay minerals to justify its identification as kaolinite.

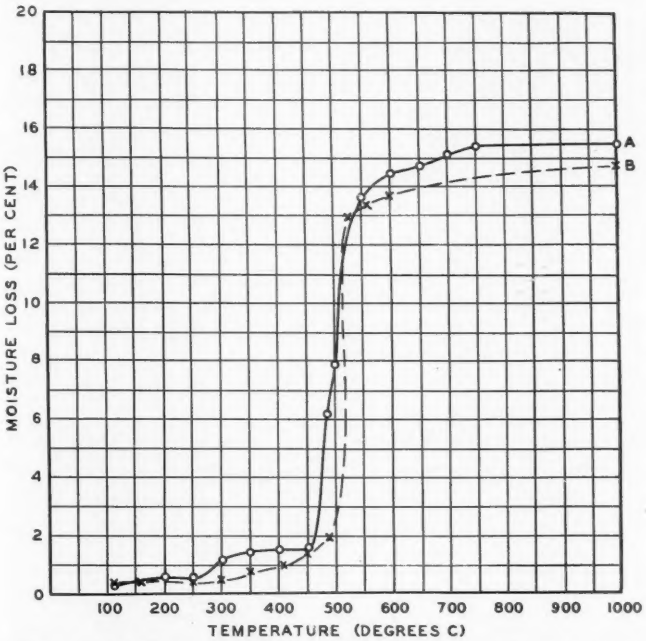

FIG. 2. Dehydration curves of kaolinite. *A*, kaolinite from Illinois coal; *B*, kaolinite from Pontiac, S. C. (Ross and Kerr, U. S. Geol. Survey Prof. Paper 165–E, 1931, p. 166.)

X-ray Diffraction Pattern.—A small amount of the hand-picked material was sent to P. F. Kerr for analysis by x-ray diffraction pattern. His comment on the results is as follows:[5]

[4] *Op. cit.*, p. 166.

[5] Kerr, P. F.: Report on X-ray Studies of 100 Selected Samples of Illinois Clays. Illinois State Geol. Survey, unpublished Ms., p. 10.

Illinois clay No. 300: The sample submitted was very small and hardly large enough to allow an x-ray diffraction pattern of satisfactory intensity. Although the pattern is weak, the lines present agree with those of kaolinite.

Although the criteria obtained by any one method of examination would hardly justify positive identification of the clay mineral in coal as kaolinite, the accordant results of optical determinations, chemical analysis, dehydration curve, and x-ray diffraction pattern are conclusive proof of its identity.

REFERENCE TO KAOLINITE IN COAL.

The presence of kaolinite in coal has not been widely recognized in studies of the composition of coal and its ash-forming constituents. Sinnatt, Grounds, and Bayley [6] subjected the white partings in certain English coals to chemical analysis and found that they were composed of calcium, magnesium, and iron carbonates. At that time "cleat" fillings in English coals were regarded as being composed entirely of "ankerites," a general term applied to these carbonates. It is probable that the coals especially studied contained only carbonate material in the vertical partings, but Lessing [7] in 1922 included a clay substance in cleat and fusain in a discussion of the distribution of mineral constituents in English coals. Later Kellett [8] and Briggs [9] discussed the presence of colloidal clay in vertical partings and fusain layers. Kellett studied the incinerated ash of coal petrographically and identified the mineral kaolinite in fusain. He believed, however, that the kaolinite impregnated the walls of the tissue of fusain, and the cell spaces were filled only with ankerites. The cleat fillings he regarded as generally being composed of ankerites

[6] Sinnatt, F. S., Grounds, A., and Bayley, F.: Origin and Nature of the White Partings in Coal Seams, as illustrated by the coals of Lancashire, England. Coal Age, vol. 20, no. 3, July 21, 1921, pp. 93–95.

[7] Lessing, R.: The Study of Mineral Matter in Coal. Fuel, vol. 1, Jan., 1922, pp. 6–10.

[8] Kellett, J. G.: The Distribution of Ash in Bituminous Coal-seams. Trans. Inst. Min. Eng., vol. 75, pp. 413–420, 1928.

[9] Briggs, H.: A Note on the Mineralogy of Coal as Suggested by X-ray Examination. Coll. Guard., Feb. 15, 1922, pp. 638–640.

although occasionally thin vertical films of clay-like material were found. Hickling [10] recognized the presence of kaolinite in secondary mineral matter of coal as follows:

> The precipitated mineral ash is very distinct in character, consisting mainly of sulphide of iron (pyrites), carbonates of lime, magnesia, iron, etc. (ankerites), and kaolinite (precipitated silicate of alumina). The pyrites and the kaolinite are found very generally filling the pores of the fusain or mineral charcoal, this being the only organic ingredient of the coal which was actually porous in character after its inclusion in the original peat. Ankerites are very familiar as the white sparry plates filling the small cleat cracks in the brighter types of coal.

He does not, however, make clear the presence or absence of kaolinite in vertical partings in coal.

In this country Thiessen [11] mentions the presence of a hydrated aluminum silicate in vertical cleats and fissures of coal. A description of one of the polished blocks pictured in his paper refers to the vertical fillings as "white non-crystalline hydrated aluminum silicate." As indicated above in this discussion, all of the kaolinite is found to be crystalline.

It is apparent from the foregoing discussion of the literature that secondary kaolinite in coal has not been petrographically identified with clarity nor have its occurrences in coal been well described.

CONCLUSION.

The physical characteristics and occurrence of the clay constituent of coal have not been well defined nor has it been specifically identified in previous discussions. It has been found during the course of investigation of mineral constituents of coal in this laboratory that secondary deposits of kaolinite may constitute more than 90 per cent. of the separable mineral matter in some parts of the coal bed and is the most prevalent mineral constituent in the total thickness of coal No. 6 in Franklin

[10] Hickling, H. G. A.: The Geological History of Coal. Fuel, vol. 10, no. 5, p. 225, 1931.

[11] Thiessen, R.: Carbonizing Properties and Constitution of No. 6 Bed Coal from West Frankfort, Franklin County, Illinois. U. S. Bur. of Mines Tech. Paper 524, pp. 4–5, 1932.

County. High contents of silica and alumina in coal ash have generally been assigned to detrital clay materials deposited contemporaneously with the formation of the peat. Detrital clay in the form of horizontal partings and in attrital layers as well as adventitious mixtures of clay from roof and floor have been considered the only source of the clay components. Recognition of the presence of secondary kaolinite in coal should be of special importance to coal-cleaning problems, to the behavior of coal and coal ash during combustion, and as an aid in evaluation of ash-correction formulae used in the derivation of unit coal values.

ILLINOIS STATE GEOLOGICAL SURVEY,
URBANA, ILL.

DISCUSSION AND COMMUNICATIONS

THE PROBLEM OF SERPENTINIZATION.

Sir:—In the November, 1933, issue of ECONOMIC GEOLOGY there appeared a very good article by H. H. Hess, entitled "The Problem of Serpentinization." In this article the not altogether new idea of the "autometamorphic" origin of serpentine by alteration "during the last stages of the same cycle of igneous activity as the intrusion of the ultrabasic" was presented. I wish to call attention to the fact that many geologists may disagree with Mr. Hess concerning the volume changes that occur during serpentinization. He says, "field evidence shows that no large volume change has occurred during serpentinization," and indicates that if any volume change has occurred it was one of shrinkage rather than of expansion. My own observations made during three years of field studies on the Island of Cuba would seem to indicate otherwise.

Areas of serpentine outcrop occur in every province of Cuba. The age of the intrusion of the ultrabasic magma is definitely fixed within narrow limits, at least in the Provinces of Matanzas and Havana. It is definitely intruded into Upper Cretaceous sediments. The intrusion was followed by a period of erosion which, by Eocene (perhaps Middle Eocene) time, had exposed many of the ultrabasic masses. The surface thus exposed was covered by Eocene and /or later Tertiary limestones and marls. The serpentine and Upper Cretaceous sediments were again exposed by the erosion of anticlinal folds in the Tertiary rocks. Many of these folds, however, have certain peculiarities not common to lateral compression folds. They are commonly dome-shaped; the flanks are apt to be rather steep and narrow, rapidly flattening to a low dip or to horizontal; and in most cases serpentine is an important areal constituent in these structural highs.

The data are not conclusive but lead to a strong suspicion that expansion of the serpentine has played an important part in the formation of these Tertiary structures. If this be so, serpentinization did not occur exclusively at the time of the emplacement of the magma but was a gradual process extending over a large part of Tertiary time and conditioned a considerable expansion.

Another evidence that the ultrabasic has undergone swelling during serpentinization is the minutely fractured, faulted, and slickensided character of the serpentine,—an invariable character of the Cuban serpentines, and a common character of serpentines in general. It indicates intensive internal differential movements such as would occur during the expansion of the mass by serpentinization.

A field observation which I cannot reconcile with the idea of the intrusion of a hydrous magma such as Hess postulates is the lack of intensive metamorphism at the serpentine contacts. Were the ultrabasic magma highly aqueous, it would be expected to effect mineralization of the adjacent rocks. In many areas where the sinuous outline of the contact is indubitable evidence of intrusion, there is no mineralization of the country rock. Chromite, iron ore, and silica deposits are common occurrences in the serpentine areas but not as phenomena of intrusion. Chromite deposits are differentiates within the body of the igneous mass; iron ore deposits occur as residual oxides from the decomposition of the serpentine; deposits of silica (opal and chalcedony), occur as residual masses on the serpentine, and occasionally silicification has penetrated the Eocene limestones which have been proved younger than the intrusive; but I know of no place where mineralization of the country rock indubitably took place during and as a direct result of intrusion.

W. D. CHAWNER.

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THE MIAMI–PICHER ZINC–LEAD DISTRICT.

Sir:—It is unnecessary to discuss further the origin of the chert associated with the ores of the Tri-State District, and this note is only in answer to the statement of Fowler and Lyden [1] that my ideas are "unsupported theories," and that I am unfamiliar with the district in question. These men evidently overlook the fact that their interpretation of the origin of the chert is a *theory*, also, and that, moreover, the evidence on which it is based has been under such successful criticism that many are discarding it for more modern views based on our increased knowledge of the origin of sediments. They make use of theories also in connection with their concept of the origin of the ores and, while I agree with them as to a deep-seated source, there are others who do not. Also, they postulate structural elements in the district which others have been unable to interpret similarly. Thus, they should recognize their own use of theories, and remember that what to them are facts may not have such weight when viewed by others. I have been studying the occurrence of chert and flint and seeking evidence for their origin for over twenty years, and have gone deeply enough into the problem to become fully aware of many elements in the origin that await further study. In the meantime, however, we all must make use of theories in interpreting these unknown elements.

As to familiarity with the district, I had the good fortune to be present at the meeting of the National Research Council's subcommittee on Ore Deposition in the Mississippi Valley, under the chairmanship of Prof. E. S. Bastin, held in Baxter Springs, Kansas, March 25–28, 1934. Surface and subsurface geology were studied and most excellent discussions were held. I was invited to discuss the origin of chert. Mr. Fowler was present and had the opportunity to criticize my views and statements at the meeting but did not do so. Under his leadership, we were conducted through the Barr mine. Obviously, as the conductor of the group, Mr. Fowler could not give as much time to me as I

[1] Fowler, G. M., and Lyden, J. P.: The Miami-Picher Zinc-Lead District. ECON. GEOL., vol. 29, pp. 390–396, 1934.

would have desired, but he did not meet my criticisms of his interpretation of the occurrence of the breccias. The features seen on this trip were wholly confirmatory of my interpretation of the occurrence and origin of chert as given in the August, 1933, number of ECONOMIC GEOLOGY. The surface features seen, especially those of the Grand Falls chert, were fully convincing to myself and others of the party that the chert was an original sedimentary deposit. I saw no new evidence on this trip to cause me to change my present views, or to make me feel that I was "unfamiliar with the occurrence of the chert in the district." I am studying material collected in the mines and on the surface and shall present its significance later. Others are now engaged in an intensive study of the Tri-State area, and it is to be hoped that their work will be fruitful in interpreting the apparently simple yet exceedingly difficult geology of the district.

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REVIEWS

Metamorphism: A Study in the Transformation of Rock-Masses. By ALFRED HARKER. Pp. ix + 360, figs. 185. Methuen and Co., London, 1932. E. P. Dutton & Co., New York, 1934. Price, $5.90.

In this work Professor Harker is concerned with metamorphism "not as a status, but as a process." Definition and classification are accordingly dismissed with scant attention, in favor of detailed consideration of the progressive changes that rocks undergo. These are due principally to changing conditions of temperature and stress. Metasomatism, or "change of substance," is recognized as an additional, but complicating factor. For the untrammeled development of the main thesis this feature is therefore—to the disappointment of the economic geologist—frequently relegated to a last place, wherein it often receives inadequate treatment.

The book is divided into two parts: the first is a study of purely thermal effects which, after three chapters on the underlying principles and on characteristic textures, proceeds with systematic and detailed descriptions of thermal effects on various rock types. Argillaceous rocks, being the most sensitive and therefore best illustrating the intensity grades of metamorphism, are considered first. In low-grade thermal metamorphism of these rocks, spotted slates are developed and xenoblastic andalusite and cordierite are characteristic. A medium grade of metamorphism finds orthoclase or (depending upon the original bulk composition) hypersthene and almandite as index minerals. In the highest grade of metamorphism, sillimanite, corundum, pleonaste and idioblastic cordierite are distinctive. Succeeding chapters deal with the thermal metamorphism of pure and impure arenaceous rocks, of pure and impure calcareous rocks, and of igneous rocks. These types are not so amenable to a simple zoning as are the argillaceous, and require specific treatment in most cases. One chapter only is devoted to pneumatolysis and metasomatism.

Part II deals with dynamic and regional metamorphism. Strain and stress are analysed and their effect on recrystallization emphasized. Regional metamorphism is considered in relation to its elements: temperature, pressure and shearing stress. Harker is not satisfied with the Grubenmann classification, "wherein the conditions that control metamorphism (of the crystalline schists) are conceived as functions of a single variable which is, ostensibly at least, depth within the earth's crust." He prefers to consider two variables: temperature with pressure (since these can be assumed to vary together), and shearing stress. However, he has earlier pointed out that "the *maximum possible shearing stress* is

a function of temperature, diminishing with rise of temperature." Commonly, in regional metamorphism, shearing stress is maintained at or about its maximum value at each temperature, and "the actual stress, being the same as the maximum possible stress, is then a function of the temperature; and, if we assume pressure also to vary with temperature, the conditions controlling metamorphism come to depend upon a single variable. This variable is temperature, though doubtless it generally corresponds with depth of cover also." As proof of the validity of this conception, the mineral zoning in the regionally metamorphosed Scottish Highlands is considered. Here it is seen that the stress-distribution is conformable with, and has been controlled by, the temperature-distribution. "The isodynamics are also isothermals."

Successive stages of advancing regional metamorphism are considered in respect to argillaceous rocks. Six zones are recognized: (1) chlorite zone, (2) biotite zone, (3) garnet zone, (4) staurolite zone, (5) kyanite zone, (6) sillimanite zone, which represents the highest grade. Similarly regional metamorphism of varying intensity in the arenaceous, in the calcareous, and in the igneous rocks is considered, but, as before, proves more difficult to systematize than in the case of the argillaceous. Concluding chapters deal with "Plutonic Intrusion in Relation with Regional Metamorphism," "Repeated Metamorphism," and "Retrograde Metamorphism."

On the whole, the point of view of this book is distinctly conservative (an interesting contrast with the author's "Natural History of Igneous Rocks," considered highly radical in its day). The book is an excellent and useful metamorphic *petrography*, but only to a limited degree is it a metamorphic *petrogeny*. Citations to the literature, however, are numerous and indicate a wider scope. Surprisingly, over 40 per cent. of them antedate 1906 (the appearance of "Die Krystallinen Schiefer"). A very considerable majority, of course, refer to British sources. It is perhaps unfortunate that more notice has not been taken of the work of Lindgren, Kemp, Spurr, Umpleby and their followers in the study of metasomatic phenomena in this country. Incidentally, American readers should be warned that Harker has gone back to Chas. Darwin for his definition of foliation, and—contrary to the present usage here, which employs the term in a very general sense to describe any parallelism in crystalline rocks—has restricted foliation to those cases where there is an apparent segregation of like minerals into bands which then show contrast in composition with adjoining bands. Thus, while "schistosity declines as the highest grade of metamorphism is approached, foliation . . . becomes more salient, and is developed on a larger scale."

The illustrations consist entirely of Harker's inimitable pen and ink drawings of selected slides. These may occasionally lack the realism of a photomicrograph, but the clarity with which significant features can be

delineated far more than compensates for this. The typography is remarkably free from errors. The writing is by a recognized master of petrographic description. Would that all text-book writers possessed Professor Harker's felicity of expression and composition. The book is one that all who work with metamorphic rocks and who look through a microscope will want to have.

IAN CAMPBELL.

Deutsches Erdöl. II Folge. By A. Moos, H. STEINBRECHER and O. STUTZER. Pp. 98, illus. 8. Ferdinand Enke, Stuttgart, 1934. Price, 9.60 M.

In the hope that some light might be shed on the source of the oil in the Hannoverian (German) oil fields, the authors secured samples from various horizons in the upper Cretaceous and subjected them to careful analyses to discover by comparison their degree of difference. They conclude that the greatest difference in character is shown to lie between the Lower Dogger and the Upper Dogger oils. Since oil horizons in the district are now known to exist in beds that are pre-salt in age, whereas most of them are in post-salt beds, it becomes of interest to determine whether the latter received their oil from the lower (Zechstein) beds or whether they and their associated Mesozoic beds are themselves the sources of their own oil. The authors were not able to answer this question to their satisfaction and so put before a number of practical oil geologists in England, the United States, Germany and a few other countries in Europe, the question as to whether the mother-substance of the Hannoverian oil originated in the Mesozoic or whether it migrated from the Zechstein (Permian). The published answers show about an even division of opinions, with the English-speaking geologists generally favoring a source within the producing beds, *i.e.* Mesozoic.

W. S. BAYLEY.

Repertoire des Mines et Gisements de France et de l'Afrique du Nord. By L. LAFILLE and V. CHARRIN. Pp. 700. Mines Carrières, Paris, 1934. Price, 100 fr.

The third edition of this well-known catalogue of the mines and quarries in France, Algeria, Tunisia and Morocco contains, in addition to the list of operations active and abandoned in these countries, also a short account of their histories, a complete reprint of the mining laws of France and its dependencies in Northern Africa, a list of concessions in all these districts, and their descriptions, and finally, a geographical index of the properties and their owners. So far as may be judged in advance, the volume appears to contain all the information necessary to a knowledge of the mining industry of the countries named.

BOOKS RECEIVED.

DAVID GALLAGHER.

Geology of Central Alberta. J. A. ALLAN AND R. L. RUTHERFORD. Pp. 41, pls. 2, 1 map in color. Alberta Geol. Surv., Rpt. 30. Edmonton, 1934. $1. General geology, description and distribution of the formations, brief economic considerations. Geologic map in color, scale 1″ to 10 miles, covering an east-west strip across Alberta between latitudes 52° 30′ and 56° 20′.

Tanganyika Geological Survey, Ann. Rpt. 1933. E. O. TEALE. Pp. 60, guide map. Dar es Salaam, 1934. 2/50. Activities and progress, with brief summaries of attainments.

Quebec Bureau of Mines, Ann. Rpt. 1932, Pt. D. Quebec, 1933. Five papers: Tabletop Map-area, Gaspé, I. W. JONES, pp. 3–32, pls. 3, 1 map; Lead and Zinc Deposits near Gaspé Bay and on Marsoui river, I. W. JONES, pp. 33–52, figs. 1, maps 1; Simard Map-area, Chicoutimi Co., B. T. DENIS, pp. 53–83, pls. 4, figs. 1, 1 map; Geology along Coulonge and Black Rivers, Pontiac Co., J. A. RETTY, pp. 83–108, pls. 4, 1 map; Geological Exploration on North Shore, Betsiamites to Manicouagan, C. FAESSLER, pp. 109–141, pls. 3, figs. 2, 1 map.

Quebec Bureau of Mines, Ann. Rpt. 1932, Pt. E. Quebec, 1933. Commercial Granites of Quebec, II.—Rivière à Pierre, Guenette, Brownsburg and other districts. F. F. OSBORNE. Pp. 72, pls. 7, figs. 3, maps 3. Descriptions of quarries.

Quicksilver Deposits of Southwestern Oregon. F. G. WELLS AND A. C. WATERS. Pp. 58, pls. 23, maps 4. U. S. Geol. Surv., Bull. 850. Washington, 1934. 30c. Geology and origin of the deposits, and descriptions of the mines.

Comité Spécial du Katanga. Annales du Service des Mines, Tome IV, 1933. Bruxelles, 1934. Three papers by A. JAMOTTE. Refers to iron deposits.

Platinum and Allied Metal Deposits of Canada. J. J. O'NEILL AND H. C. GUNNING. Pp. 165, figs. 9, pls. 1. Canada Geol. Surv., Econ. Geol. Ser. 13. Ottawa, 1934. 50c. History, properties, uses, and mineralogy; general character and origin of deposits of platinum group metals; occurrences in Canada; world occurrences; production statistics.

Witwatersrand System in the Klerksdorp-Ventersdorp Area. L. T. NEL. Pp. 32, figs. 5. South Africa Geol. Surv., Geol. Ser. Bull. 1. Pretoria, 1934. 1s. Preliminary stratigraphic report.

Andalusite Sands of the Western Transvaal. F. C. PARTRIDGE. Pp. 16. South Africa Geol. Surv., Geol. Ser. Bull. 2. Pretoria, 1934. 6d.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

SCIENTIFIC NOTES AND NEWS

H. B. Maufe has retired as Director of the Geological Survey of Southern Rhodesia, after twenty-five years of service, during which he has built up an internationally known organization. All Rhodesians regret his departure to England.

H. Foster Bain has retired from the position which he has held for three years as managing director of the Copper and Brass Research Association.

J. F. Walker, of the Canadian Geological Survey staff, has succeeded J. D. Galloway, resigned, as Provincial Mineralogist for British Columbia.

David White, who for 48 years has been connected with the U. S. Geological Survey, received from the Institute of Petroleum Technologists, at the summer meeting in London, the Sir Boverton Redwood Medal for distinguished service.

B. Lightfoot succeeds H. B. Maufe, retired, as Director of the Geological Survey of Southern Rhodesia.

W. P. Alderson has returned to Montreal after two years of prospecting work in Kenya and Uganda.

D. H. McLaughlin, of Harvard University, lectured before the Geological Club of Yale University on November 22 on the Homestake Mine.

Fred E. Johnson, recently with the U. S. Geological Survey, has joined the staff of the Arizona Consolidated Mines Company.

P. B. Nye, Government geologist, Tasmania, is to conduct a photographic geological-geophysical survey in northern Australia for the Commonwealth Government.

Robert W. Karpinski is now associate professor of geology and geography at Indiana State Teachers' College, Terre Haute, Indiana.

Dale L. Pitt, after several years on the staff of the Premier Mine, British Columbia, has gone to Australia to take charge of development and operation of a property owned by American Smelting & Refining and Premier Gold Mining Company.

Frank Reeves, L. G. Putnam, and W. A. Findlay are associated with D. Dale Condit in work in Australia for the Oil Search, Ltd., of Sydney, and are drilling for oil in the Roma district of Queensland.

The Louisiana legislature in 1934 passed a measure creating a State Geological Survey as a Division of the Department of Conservation. Cyril K. Moresi has been appointed State Geologist, and James H. Mc-

Guirt Assistant Geologist. Since the Gilbert D. Harris survey (1898–1909) no State geological organization has existed in Louisiana.

The Canadian Institute of Mining and Metallurgy held its annual Western meeting at Calgary, Alta., September 13 and 14, and at Banff, September 15, when the Dowling Memorial, in memory of Donaldson B. Dowling, was dedicated in Banff National Park.

The American Association of Petroleum Geologists will hold its 20th annual meeting in Wichita, Kansas, March 21–23, 1935. The general chairman of the local committee is E. C. Moncrief, Derby Oil Company, Wichita.

The Geological Society of America will hold its forty-seventh annual meeting at the University of Rochester, River Campus, Rochester, N. Y., December 27–29. The presidential address of W. H. Collins and the smoker will be on the evening of December 27, and the banquet on December 28. The Mineralogical Society of America and the Paleontological Society will hold meetings at the same time. Professor Harold L. Alling is in charge of the local arrangements.

The Society of Economic Geologists will hold its annual meeting this year with the American Institute of Min. and Met. Engineers at New York, February 18–21, 1935. Titles and abstracts of papers should be sent to W. B. Heroy, Consolidated Oil Corporation, 45 Nassau St., New York City.

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